THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

Designing for Safe Maritime Navigation

Studying Control Processes for Bridge Teams

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Abstract

Several technological advances have been seen the maritime domain to achieve higher operational efficiency and to address the generally recognised causes of most maritime accidents. The International Maritime Organization (IMO) endorses the use of best available technology to “drive continuous improvement and innovation in the facilitation of maritime traffic” in line with the goal of sustainable development. It is commonly acknowledged that modern technology revolutionized marine navigation, and presently it has a large potential to increase safety in navigation. However, the incorporation of new technologies in support of navigation also brought unforeseen critical consequences, contributing to unsafe practices, or even to accidents or incidents. Several issues were associated with human factors. To properly address the adoption of the newest technology in support of safe navigation, IMO established the e-navigation concept, currently under implementation.

The complexity of the maritime socio-technical system requires novel theoretical foundations, since many of the present framework rely on the analysis of accidents. The design of complex maritime navigation system must take place on several levels, providing different perspectives over the system problems. The evaluation and design of technologies envisaged by the e-navigation concept requires a better understand of how teams perform the navigation work in the pursuit of safe navigation. This study attempts to provide a better understanding on how maritime navigation is currently done on-board, considering the overarching elements and their interactions. In maritime navigation safety is a transverse issue, and that is why we need to know the conditions for safe navigation to improve the design of ship navigation control.

The work supporting this thesis was focused on: (i) understanding how navigation is done and to perceive by the practitioners, (ii) understanding interactions between humans and technological interfaces, and (iii) understanding the relevant soft skills for the navigation functions. To address these topics, data was collected from expert practitioners such as navigators, pilots and instructors, thru semi structured interviews and questionnaires. The mains contribution of this study lies in presenting a framework of maritime navigation, exploring the control processes in the different levels of the maritime socio-technical system. In the view of safe operations, interactions between stakeholders are clarified, trying to determine how they influence safe navigation. This systemic view is then analysed from the perspective of the ship, considering it as a Joint-cognitive system (JCS). It is proposed that this JCS comprises 5 control levels: reactive, proactive, planning, strategic and political-economical. Planning is considered a fundamental process in the maritime Socio-technical system, because it facilitates the interactions between the different control level. It also increases the integrity of communications and enhances the predictability of the different control agents. New directions are proposed to improve the design of navigation system, recommending new roles for human and automated agents, and presenting a new conceptual navigation display.

Keywords: e-Navigation, navigation control, pilotage, human factors, Socio-technical Systems, safety, joint cognitive systems

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List of publications

This thesis is based on the work presented in the following papers and presentation:

Paper I **What is maritime navigation? Unfolding the complexity of a Socio-technical System**
Conceição, V. P. da, Dahlman, J., & Navarro, A. (2017).
Human Factors and Ergonomics Society Annual Meeting, 9-13 October 2017, Austin, USA.
Peer-reviewed and published in the conference Proceedings *Human Factors and Ergonomics Society Annual Meeting Vol 61(1), 267–271.*

The author of this thesis developed the presented ideas, took part in the planning of the paper, performed the field work., and was responsible for the interpretation of the results and writing the paper.

Paper II **Visualization in Maritime Navigation: A Critical Review**
Conceição, V. P. da, Carmo, M. B., Dahlman, J., & Navarro, A. (2017). *8th International Conference on Applied Human Factors and Ergonomics, 17-21 July, Los Angeles, USA*
Peer-reviewed and published in book chapter in *Advances in Human Aspects of Transportation. AHFE 2017. Advances in Intelligent Systems and Computing, vol 597, 199-212. Springer, Cham*

The author of this thesis developed the presented ideas, took part in the planning of the paper, performed the field work., and was responsible for the interpretation of the results and writing the paper.

Paper III **Development of a Behavioural Marker System for Rating Cadet's Non-Technical Skills**
Conceição, V. P. da, Basso, J., Lopes, F. C., & Dahlman, J. (2017). *12th International Symposium on Marine Navigation and Safety of Sea, 21-23 June 2017, Gdynia, Poland*
Peer-reviewed and published in the *International Journal on Marine Navigation and Safety of Sea Transportation, Vol. 11(2)*

The author of this thesis contributed to the presented ideas, took part in the planning of the paper, contributed to the planning of data collection, analysis, and interpretation of the results and was responsible for writing the paper.

Table of contents

List of figures

List of tables

Abbreviations and acronyms

ACCSEAS	ACCessibility for Shipping, Efficiency, Advantages, and Sustainability
AIS	Automatic Identification System
ARPA	Automatic RADAR Plotting Aid
BNWAS	Bridge Navigational Watch Alarm System
BRM	Bridge Resource Management
COLREG	International Regulations for Preventing Collisions at Sea
CRM	Crew Resource Management
CSE	Cognitive System Engineering
ECDIS	Electronic Chart Display and Information System
ENC	Electronic Navigational Charts
ETTO	ETTO Principle - Efficiency-Thoroughness Trade-Off
GMDSS	Global Maritime Distress and Safety System
GMN	Global Maritime technologies cooperation centres Network
GPS	Global Positioning System
HFACS	Human Factors Analysis and Classification System
IALA MBS	IALA Maritime Buoyage System
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IBS	Integrated Bridge System
IBS	Integrated Bridge System
IHO	International Hydrographic Association
IMO MSC	IMO Maritime Safety Committee
IMO NCSR	IMO Sub-Committee on Navigation, Communications and Search & Rescue
IMO	International Maritime Organization
INS	Integrated Navigation Systems
ISO	International Organization for Standardization
ITU	International Telecommunication Union
JCS	Joint Cognitive Systems
KPI	Key Performance Indicators
KSI	Key Safety Indicator

LOA	Length overall (ship)
MAIB	Marine Accident Investigation Branch
MET	Maritime Education and Training
NASA	National Aeronautics and Space Administration
NAVSIM	Navigation Bridge Simulator
NMEA	National Marine Electronics Association
NTS	Non-Technical Skills
NVivo	NVivo - software for qualitative data analysis
OOW	Officer of the Watch
RE	Resilience Engineering
SA	Situation awareness
SENC	System Electronic Navigational Chart
SOLAS	Safety of Life at Sea (IMO convention)
STCW	Standards of Training, Certification and Watchkeeping for Seafarers (IMO convention)
STE	Socio-Technical Environment
STS	Socio-technical Systems
STSE	Socio-technical Systems Engineering
VTS	Vessel Traffic Service
WMO	World Meteorological Organization
WWNWS	World Wide Navigational Warning Service

1 Introduction

1.1 Background

Over the last decades, maritime navigation has witnessed the introduction of huge technological advances. This was done to achieve higher operational efficiency and to address the generally recognised causes of most maritime accidents (IMO, 2006b). Digital information and computing technology brought the capability to deal with a large amount of data and information, facilitating system integration and ultimately assisting the navigation tasks. Technology has always been a driving force in human evolution and social change. Logically, the same happened with seafaring (Hahn, 2014) and the strategic plan of the International Maritime Organization (IMO)[1] endorses the use of best available technology to "drive continuous improvement and innovation in the facilitation of maritime traffic" in line with the goal of sustainable development (IMO, 2015a, 2015b). In order to address the incorporation of the newest technology in support of safe navigation, namely communication and information technology, IMO established the e-navigation concept, which is under implementation (IMO, 2014c).

There is no doubt that modern technology revolutionized marine navigation, and presently it has a large potential to minimize errors and endorse increased safety in navigation (ALLIANZ Global Corporate, 2012). However, the incorporation of new technologies in support of navigation has also brought unforeseen critical consequences, contributing to unsafe practices, or even to accidents or incidents (Dekker, 2014; IMO, 2006a; Mills, 2006). Navigational errors and failures have been a significant element in several maritime incidents (MAIB, 2004, 2006) and human errors were identified as a dominant factor in maritime accidents, where failures of situation awareness, assessment, planning and communication were a dominant issue (Baker & McCafferty, 2005; Macrae, 2009). As an example, a report on the investigation of a recent grounding incident concluded that the available navigation system "had not been used as expected by the regulators or equipment manufacturers"(MAIB, 2017). Conversely humans are also a source of success, due to their unique capability to be adaptive, to learn, to collaborate, to be responsible, and to be creative, even under stressful situations (Woods & Hollnagel, 2006). Under these circumstances, it is not surprising that human factor research has become increasingly relevant in the maritime domain (Luo & Shin, 2016).

Several studies reinforced the awareness that human factors are the main root of maritime accidents (Berg, 2013; Chauvin, Lardjane, Morel, Clostermann, & Langard, 2013; Grech, Horberry, & Koester, 2008; Hetherington, Flin, & Mearns, 2006; IMO, 2009a; MAIB, 2006; Martins & Maturana, 2010). Several issues are associated with those failures, like over-reliance on automation, over-confidence in the data presented by automated control systems, lack of understanding of inherent weaknesses of automated control systems, ergonomic design considerations, human-computer interface, development and maintenance of situation awareness, and information overload (Bainbridge, 1983; Hancock et al., 2013; Klein, Woods,

[1] International Maritime Organization – is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships.

Bradshaw, Hoffman, & Feltovich, 2004; Parasuraman, Molloy, & Singh, 1993). The overall complexity of technological support systems and regulatory framework for marine navigation increases the importance harmonized standards and training requirements. As result of the shortcomings in human performance and its relation to technology, IMO started to define policies and regulations that would address human factors[2] (IMO, 2002a, 2006a, 2007b, 2014b).

By 2009, based on an initial proposal from several countries (IMO, 2005) and considering contributions from industry and other relevant organizations, IMO approved the “Strategy for the development and implementation of the e-navigation concept” (IMO, 2009a), with the following definition: "E-navigation is the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment."

Notwithstanding IMO’s increased attention towards human and organizational errors (IMO, 2002a, 2014b), along with the promulgation of policies for the adoption of good ergonomic principles as part of the e-navigation strategy (IMO, 2014c), most of the identified problems that are human factor related are still in place (Christoffersen & Woods, 2002; Hollnagel, 2012; Lützhöft, Grech, & Porathe, 2011; Praetorius, Kataria, et al., 2015). Simultaneously, it has become clear that human factors are essential when designing complex information systems to support critical operations (Flach, 2012; Hetherington et al., 2006; Perrow, 1984; Vicente, 2004). Some figures show that the increased digitalization of maritime industry, witnessed over the last two decades, is not followed by a decreasing number of maritime accidents (Luo & Shin, 2016). New types of failures are emerging due to the ever-growing complexity of the maritime Socio-technical System, related with the incorporation and integration of new information systems, connecting on-board, shore systems and human operators (Lützhöft & Dekker, 2002). The aim of improving safety and efficiency of maritime operations can only be reached by further understanding of the dynamics that are occurring in the ever-changing working context (Hoffman, 2007).

Regarding the navigational tasks performed on-board, the quality of the anticipated e-navigation solutions must be tested, monitored and evaluated in respect to the context where they are to be used, applying the human factor principles and processes (Costa, Lundh, & MacKinnon, 2018; Costa & Lützhöft, 2014; Porathe & Shaw, 2012). For a human-centred approach some of the essential aspects to be considered are the interactions, collaborations, natural cognitive response and workload reduction. According to Hutchins (1995) the thinking and the decision-making processes are not only dependent of the individual himself, but are also socially distributed among the elements of a team, and among the individuals and the cognitive tools of the Socio-technical Systems (framework of distributed cognition). Consequently, the study of maritime navigation needs to consider the system, composed by

[2] Human factors are commonly mentioned as human element within the IMO regulatory framework.

human and technological elements, as the unit of analysis (Vicente, 2004; Woods & Hollnagel, 2006).

Safety of navigation is facing new challenges, such as increasing number of ships, as well as of ship size and operational speed or even the emergence of unmanned vessels. At the same time new stakeholders are occupying the maritime space, such as offshore fish farms, wind energy farms, and other renewable energy systems (Lloyd’s Register, QinetiQ, & University of Southampton, 2015; QinetiQ, Lloyd’s Register, & University of Strathclyde, 2013). Cumulatively, mariners are global actors, and they are systematically posed with different regulations and service levels all over the world, regardless of vessel class or type of operation. These globalization processes brought new safety implications, such as the effects of standardisation, digitalization, self-regulation, externalization and financialization (Le Coze, 2017). The new era of maritime navigation research must be multi-disciplinary, use multiple data sources, and adopt advanced research methods to address complex interactions, the context of operations, new technology, human behaviour, and shipping stakeholders’ interest (Luo & Shin, 2016).

A large range of changes and innovations processes derive from numerous accident analysis models, yet it has been recognized that novel theoretical foundations are needed to address the complexity of recent systems (Mullai & Paulsson, 2011, p. 1591). Component’s tasks and functions should be drawn from the system mission statement, and only then it would be possible to design the requirements of the new individual components (Meister & Enderwick, 2002). The design of complex maritime navigation system must take place on several levels, providing different perspectives over the system problems, giving a holistic view of the system development, with system components coherently arranged (Lurås, 2016). To evaluate and design the technologies envisaged by the e-navigation concept we need to better understand how teams perform the navigation work in the pursuit of safe navigation.

1.2 Thesis purpose

1.2.1 Objective of the thesis

The aim of the research proposed here is to understand how maritime navigation is currently done on-board, considering the overarching elements and their interactions. These include the navigation team, the vessel, shore-based services and other actors sharing the same space, together with the anticipated e-navigation supporting information system. This thesis intents to deliver a deeper understanding and characterization of the maritime navigation domain. It focuses on how navigation is carried out by expert mariners from diverse types of vessels or organizations.

This research embraces IMO’s solutions S1 (improved, harmonized and user-friendly bridge design) and S3 (improved reliability, resilience and integrity of bridge equipment and navigation information) stated in the e-navigation Strategy Implementation Plan (IMO, 2014c), as it is intended to provide a framework to model navigational control in a conceptual e-navigation bridge.

This research will adopt a system approach to study navigation in the ship domain. The ship bridge is considered as a socio-technical system (Grech et al., 2008), and the emphasis is set on the control of navigation and on the complex interaction among the current and foreseen agents within the ship, both human and non-human. The theoretical framework is based on concepts derived from systems theory, Joint activity, activity theory, Socio-technical Systems and Joint Cognitive System. The results aim to provide guidance for design solutions, reflecting improvements in the Socio-technical System performance

1.2.2 Research questions

This study considers maritime navigation as an activity performed by a Joint Cognitive System (JCS) as defined by Hollnagel and Woods (2005) embedded in a socio-technical system. It aims to understand how navigation is performed by navigators and provide guidance for new system arrangements that contribute to safe navigation. To achieve the objectives, the following questions will guide the research activities:

1. How, at a deeper level, is maritime navigation executed today?
2. What are the conditions for safe navigation?
3. How can we improve the design of ship navigation control for safe and efficient navigation?

1.3 Appended papers

This thesis is based on three research papers, that are constituents of a larger research work on maritime navigation performance within e-navigation. All papers attempt to answer the research questions, as shown in Figure 1, and are tackling the unit of analysis (ship's navigation team activity) by different perspectives.

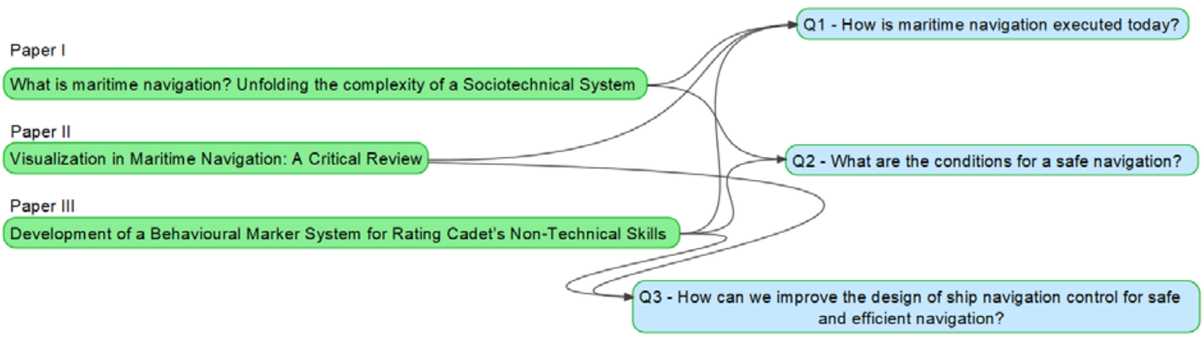

Figure 1 - Relations between research questions and appended papers.

Paper I: Describes how navigation is performed on naval, commercial, coast guard and sea rescue vessels. It aims to perceive the practice of maritime navigation from the ship's perspective. The research contributes to the development of the contextual framework, establishing the interaction between maritime stakeholder's motivations and decisions made in maritime navigation. It also helps to clarify how safety is achieved and perceived by the different components of the socio-technical system.

Paper II: describes the interaction between humans and specific technological interfaces. The study was oriented to the most common information system which are visual displays. The research aims to assess some specific system design concepts. These concepts can later be used, together with the results of papers I and III, to develop new navigation methodologies.

Paper III: Considers how non-technical skills are used by teams in support of navigation functions and how they can be developed in simulators. This research also provides valuable insights on training needs and identification of new strategies to be applied in Maritime Education and Training (MET).

2 Maritime Navigation

2.1 Describing maritime navigation

Maritime navigation is an activity embedded in a very complex, large scale and multinational socio-technical system (Grabowski, You, Song, Wang, & Merrick, 2010; Mansson, Lützhöft, & Brooks, 2016; Schröder-Hinrichs, Praetorius, Graziano, Kataria, & Baldauf, 2015). On sea going vessels, teams are commonly multicultural, available technologies and systems vary, communication and interactions rely on electronic and digital systems, and the natural environment can be very stressful. Besides these issues, daily uncertainties and disturbances make maritime navigation a dynamic and complex critical system (Perrow, 1984; Vicente, 2004).

Onboard, the bridge team must guide the vessel from one location to another safely and efficiently. To do it safely, it must avoid all kinds of hazards, e.g. traffic or bad weather, to avoid damages to the ship or to the natural environment. They must also be efficient to minimize the operational cost. As represented in Figure 2, any voyage requires at least three concurrent functions: planning, track keeping and hazard avoidance. Prior to the voyage, the team must not only compute its length and duration, but also to appraise the location of dangers and the available resources to set the best route. During the execution, they must certify that the plan is followed and make the necessary arrangements to avoid new dangers or deal with new contingencies.

Figure 2 - Conceptual representation of navigation main functions.

Regardless of the navigation methods and available tools, the basic problems of navigation always involve the determination of position, direction and distance (Cutler, 2004). In the maritime domain, this requires knowledge of position, direction, time and hazards. Figure 3 depicts some of the characteristics of these elements, where distance is related to time, speed and positions. One should note that sometimes it's more important to know how the ship is in relation to the hazards than knowing the ship's absolute position, i.e. its geographical coordinates. For instance, when the ship sails within the channel's marked limits, the precise position may not be known. However, it is certainly transiting within a safe area.

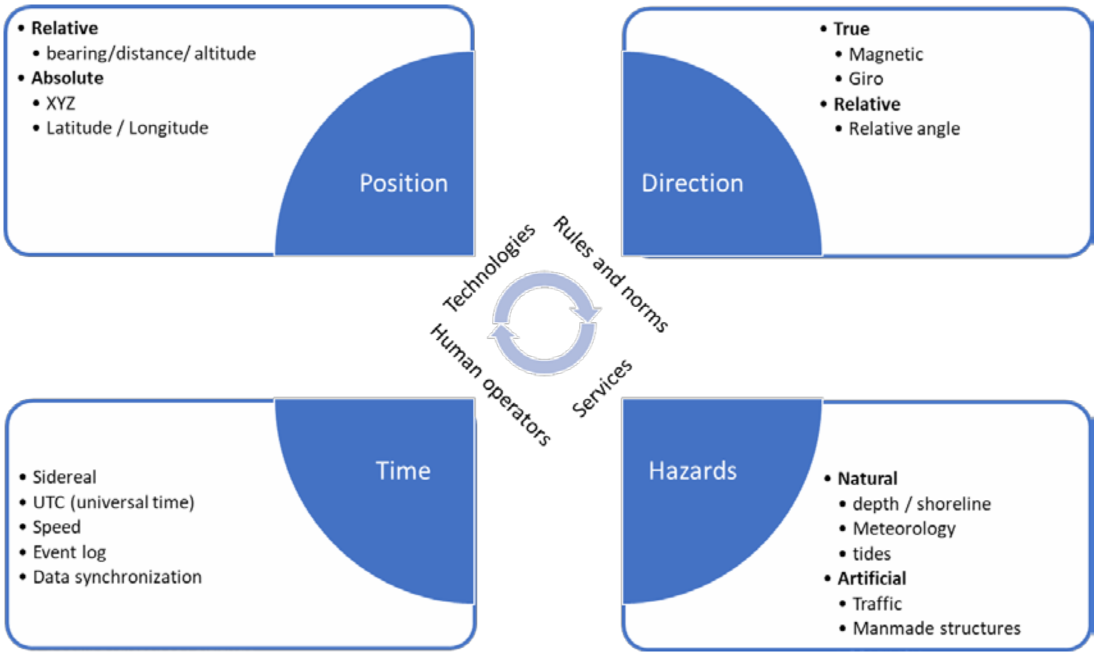

Figure 3- The basic elements of navigation.

To solve navigation problems, the navigator and his team have at their disposal several instruments and technologies, regulations and norms to follow, human resources and shore based services from different sources (Copetrans & CETMO, 2012; Morgas, Kopacz, & Urban, 2008). Onboard, the technological tools help with the observations required for the determination of position, direction and time. The position may be determined by several means, for instance with a sextant, an accurate clock and astronomical publications, or by electronic means using a GPS receiver. To relate ship position with hazards, the navigator needs to plot the position on a nautical chart, or to combine a GPS with an electronic chart system (ECDIS – Electronic Chart Display and Information System). Another way can be through direct visual observation or by taking bearings and distances, using compasses and RADARs.

Nautical charts, as other nautical publications, are published by competent national authorities and are an example of required shore-based services. Nautical charts and sailing directions provide information on dangers, how to avoid them, and support the determination of positions. Other types of services are available to support the seafarers in the knowledge of existing dangers. Weather services provide information on existing and forecasted weather. Aids to Navigation authorities manage and provide visual aids, such as lighthouses and buoys, that are used to guide and inform the mariner about dangers. Other services, like the World Wide Navigational Warning Service (WWNWS) (IMO, 1991, 2008) and the Global Maritime Distress and Safety System (GMDSS) (IMO, 1995a), exist to alert the mariner about new dangers that were not known or predicted when the passage plan was made, such as storms, breakdown of visual aids, ships in danger or wrecks. This is technically known as Maritime Safety Information (IMO, 2009b).

Other systems are available to provide representation of the surrounding, like the RADAR used to detect and track other vessels or coastline, and the Automatic Identification System (AIS) to automatically share ship's information such as name, position, course and speed. Shore based services, like Vessel Traffic Service (VTS) can also support the understanding of nearby situations and provide guidance.

The coordination of all these services and activities is supported by a regulatory framework, under the governance of IMO. SOLAS (Safety of Life at Sea) Convention, published by IMO, is the core document and Chapter V focus on the Safety of Navigation for all vessels at sea. It sets the general requirements for several nautical services, namely:

- Navigational warnings: to alert the mariners about any danger;
- Meteorological services and warnings: to disseminate weather information and warn ships of gales, storms and tropical cyclones.
- Hydrographic services: to publish, disseminate and keep up to date all nautical information necessary for safe navigation;
- Ships' routeing: to establish an international and mandatory systematic way to establish predetermined routes that ships must follow to avoid hazards to navigation at sea;
- Vessel traffic services: to assist traffic through navigation advice and assistance on request, and providing traffic organisation services in some areas;

The same Chapter V of SOLAS, also establishes:

- Principles relating to bridge design, design and arrangement of navigational systems and equipment and bridge procedures;
- Carriage requirements for shipborne navigational systems and equipment;
- Rules for conducting safe navigation.

Another relevant convention adopted by the IMO and related with execution of navigation, is the Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) (IMO, 2011), establishing common standards of competence for ship masters and other seafarers. To prevent collisions at sea, vessels have to follow the Collision Regulations (COLREGs) (IMO, 2003a). Finally, to ensure safe operation of ships and for pollution prevention, IMO issued guidelines and standards for shipboard safety management: the International Safety Management (ISM) Code (IMO, 2014a).

While IMO has established the general principles for shore-based services and shipboard arrangements, more comprehensive recommendations and guidelines are provided by other international organisations. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) deals with Aids to Navigation, including VTS, AIS and differential global positioning systems (DGPS). The International Hydrographic Organization (IHO) establishes standards for the production and provision of nautical charts and publications, together with electronic charts.

The size and organization of the bridge team varies depending on the type of vessel, operation and navigation area. On smaller boats or fishing vessels, a single operator commonly deals with all the tasks. As they become larger or engaged in specific operations, two operators are needed, distributing the tasks of navigation, piloting (taking the control of the heading and speed) and command. This arrangement is seen in numerous types of vessels and operations, some requiring precise coordination, like high speed navigation (Forsman, Dahlman, & Dobbins, 2011). In some cases, the ship's team receives the collaboration of a harbour pilot, who provides enhanced local knowledge and facilitates local coordination with VTS and tugs. This joint activity has been explored by recent empirical studies (de Vries, 2017; Mansson et al., 2016; Mikkers, Henriqson, & Dekker, 2013; van Westrenen, 1995; van Westrenen & Praetorius, 2014; Wild, 2011).

Considering the minimum-manning standards for SOLAS vessels, on the smallest vessels navigating off coast, we may find the Master, one helmsman plus a lookout. When in confined waters, the bridge team organization mostly depends on the ships manning (Wild, 2011), however we expect to have, at least, the master in command, a conning officer (control of the ship), a harbour pilot, a deck officer monitoring the position, a deck officer for anti-collision assessment (in some cases a single deck officer is in charge for both position and anti-collision functions), a lookout and the helmsman. External communications are usually undertaken by the master or pilot, and larger vessels may designate an additional deck officer.

On navy vessels, we find larger teams, with very similar navigation equipment to the one used by SOLAS ships, even though some may have enhanced capabilities and they don't have to comply with most of the international standards. Hutchins' (1995) study gives a very compressive description of the bridge and navigation team work of navy ships. On sea going voyages, the bridge team usually comprises one or two officers, one chief at the navigation chart, one helmsman, one rating for propulsion controls, two lookouts and one rating for event log. When in confined waters, the navigation team, headed by the ship's navigator, takes control and the bridge team is reinforced with one officer for anti-collision and another for position monitoring. The captain is on the bridge on these occasions.

Crew Resource Management (CRM) training programs were developed in aviation, to improve safety and efficiency in operations, using all available means such as information, equipment, and people (Kanki, Helmreich, & Anca, 2010, p. 5). This instructional framework was later introduced in the maritime context, with the designation of Bridge Resource Management (BRM), sometimes also referred to as Bridge Team Management (Swift & Bailey, 2004). This framework has been used to develop bridge navigation team's performance through the enhancement of a shared mental representation (Brun et al., 2005). However, some studies have identified some lack of effectiveness of BRM in comparison to CRM in other domains (O'Connor, 2011; Salas, Wilson, Burke, & Wightman, 2006). O'Connor (2011) proposes that this is due to a deficient assessment of maritime user's needs and subsequent fragilities in adapting the CRM program framework.

Due to the advances in information and communication technologies and global satellite positioning systems, along with the establishment of higher performance standards of efficiency and safety, new systems were introduced on the bridge since middle 90’s, namely:

- The Global Navigation Satellite System (GNSS) receiver (e.g. GPS, GLONASS, DGPS) (IMO, 2000a, 2000b, 2000c, 2000d, 2001) for use at all times throughout the intended voyage to establish and update the ship’s position by automatic means.
- The Automatic RADAR Plotting Aids (ARPA) (IMO, 1995c, 2004) represents an enhancement of the traditional RADAR, to improve collision avoidance performance, by reducing Officers’ of the Watch workload, enabling automatic and continuous detection and tracking of targets, providing accurate and rapid computations with alerts.
- The Electronic Chart Display and Information Systems (ECDIS) (IMO, 1995b, 1998, 2006c) which is a navigation information system, that can comply with the requirement of the up-to-date paper nautical chart set by the SOLAS Convention, displaying selected information from a System Electronic Navigational Chart (SENC) with positional information from navigation sensors to assist in route planning and route monitoring.
- The Integrated Bridge System (IBS) (IMO, 1996) which allows centralized access to sensor information or command/control from workstations, supporting passage execution, communications, machine control, cargo control, safety and security. The IBS usually includes: autopilot, Dual Radar/ARPA, Gyrocompass, Position fixing systems, Dual ECDIS setup, Conning Display (displaying information that summarises the important navigational sensors), Power distribution system, Steering gear and GMDSS.
- The Integrated Navigation System (INS) (IMO, 1998, 2007c) which supports the navigator by providing enhanced functional capabilities and information needed to plan, monitor or control the movements of the ship. This system was designed to address mariners’ situation awareness and workload, by evaluating inputs from several independent and different sensors, combining them to provide information, giving timely warnings of potential dangers and degradation of integrity of this information.
- The Bridge Navigational Watch Alarm System (BNWAS) (IMO, 2002e) monitors the awareness of the OOW and automatically alerts the Master or another qualified OOW if for any reason the OOW becomes incapable of performing his duties. This is achieved by a series of indications and alarms to alert first the OOW and, if he is not responding, then to alert the Master or another qualified OOW.
- The Automatic Identification Systems (AIS) (IMO, 2002c, 2002d, 2003b, 2007a) assists the bridge team in vessel identification, target tracking and information exchange with other vessels and shore services, using digital data-link communications. Thus, it aims to improve situational awareness by the provision of additional information derived directly from ship-born digital systems. Yet, not all ships are required to carry this system, and it has several integrity issues, related with data availability and reliability (Calder & Schwehr, 2009; Harati-Mokhtari, Wall, Brooks, & Wang, 2007; Last, Bahlke, Hering-bertram, & Linsen, 2014; Schwehr, 2011).

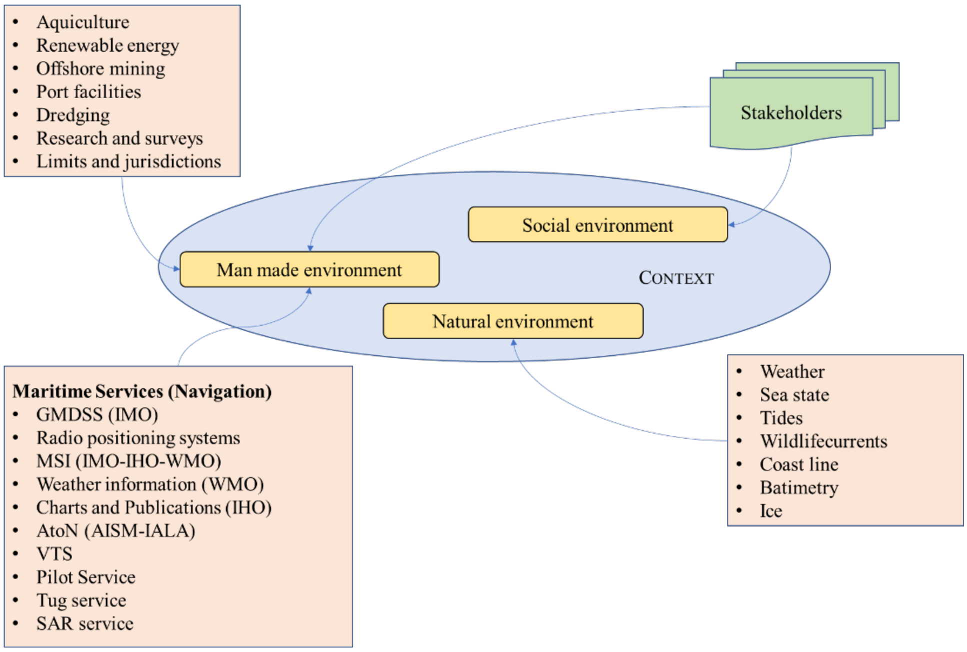

Figure 4 - Context elements of maritime navigation.

Summarizing, maritime navigation is a safety critical complex activity, occurring in a context shaped by social influences, conditioned by manmade structures and exposed to natural circumstances. The diagram in Figure 4, depicts some of the numerous elements which contextualize the settings of maritime navigation. The next section provides a closer look at relevant players and their influence in maritime navigation.

2.2 Who are the players and stakeholders?

The arrangements made to support maritime navigation functions are influenced and managed by numerous players, each with their own motivation and goals. The diagram in Figure 5 tries to represent the stakeholders and their main relations. Clarifying who are the stakeholders provides a better understanding of what drives and shapes the way maritime navigation is done. Some players are always present, like the mariner who will use the new technologies or the shipping industry that will have to purchase, manage and make a profit with the ships.

Other stakeholders have regulatory roles, providing norms and guidance that must be followed by all. These are governmental agencies and national or international policy makers, e.g. IMO, International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), International Hydrographic Association (IHO), World Meteorological Organization (WMO). The provision of technology to support navigation requires industry and researchers. The establishment and maintenance of technical standards for the construction and operation of ships is done by classification societies, and other international specialized agencies such as the International Organization for Standardization (ISO), International Telecommunication Union (ITU) and National Marine Electronics Association (NMEA).

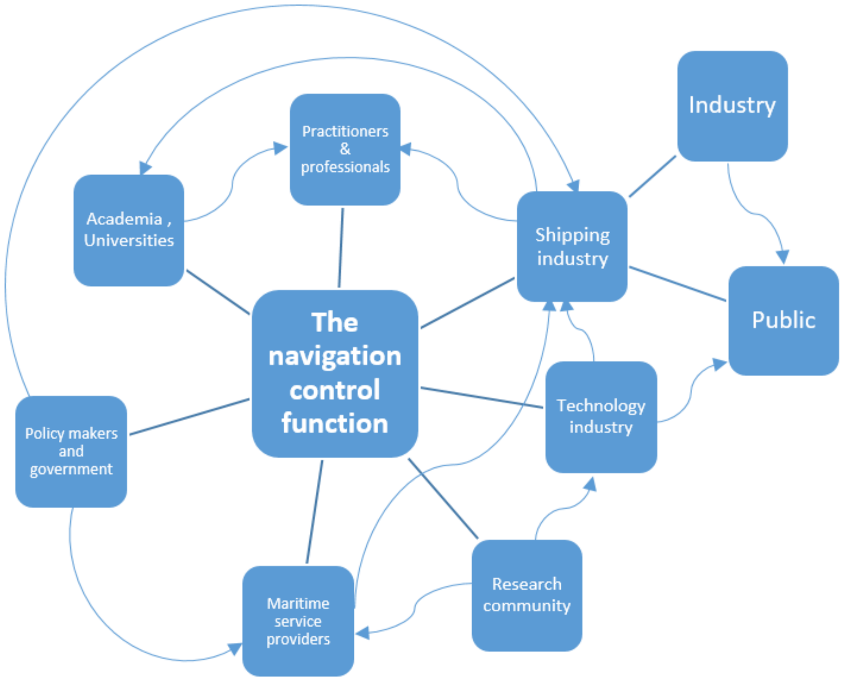

Figure 5 - Framework of the Stakeholders related to the topic of the research.

The shipping industry, once handed the norms to perform their activities, will have to set the professional requirements for the practitioners, which will be used by universities when designing their courses. Additionally, we may find second level stakeholders, such as the public and general industry, since the shipping industry's impact over the labour market and over the cost of the tradable goods is quite significant. Lastly, some of these stakeholders may have divergent interests and motivations, which need to be considered when assessing new technologies and regulations. On December 2017, to assure leadership in the promotion of ship energy-efficiency technologies and operations, IMO launched the creation of a global network of centres of excellence in marine technology (Global Maritime technologies cooperation centres Network - GMN).

2.3 Maritime Navigation in the XXI century

Over the last two decades, ship bridges have changed very much due to the rapid development of new technologies. These changes are inducing silent transformations in the navigator's role, which demands a review of the maritime navigation process (Belev, 2010; Chawla, 2014; Kopacz, Morgaś, & Urbański, 2004; Peterson, 2002). More recently, automation, broad band communications and internet as led to the possibility of using remote and unmanned vessels, bringing additional challenges (Wahlström, Hakulinen, Karvonen, & Lindborg, 2015).

This trend in maritime navigation technology, highlighted in Figure 6, has opened-up a discussion on how to redefine the way ships are operated and designed. Despite the common acceptance of the advantages brought by digital information and computing technology, the overall complexity of technological support systems and regulatory framework for marine navigation emphasizes the need for a new system design. The increased complexity of modern technological system is an important driver of Cognitive System Engineering (CSE) development (Hollnagel & Woods, 2005).

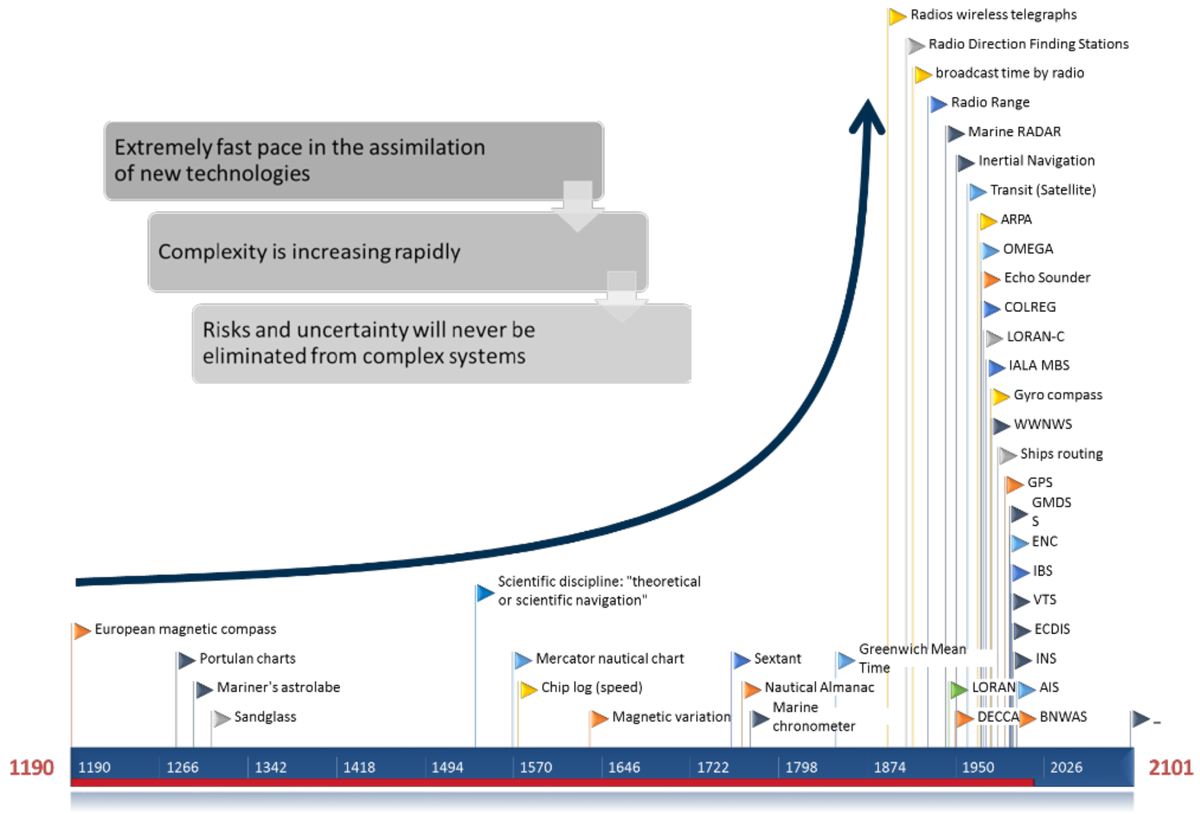

Figure 6 - Time line visualization of the trend in maritime navigation technologies and techniques.

The role of the navigator is shifting to tasks more related with setting goals, planning and monitoring, since execution and surveillance are being undertaken by automated systems such as the autopilot or automatic detection and tracking RADAR (ARPA - Automatic Radar Plotting Aid). From the taxonomy proposed by Endsley and Kaber (1999; Kaber & Endsley, 2003), this arrangement of functions between human operators and automated systems corresponds to higher levels of human machine dependency: Automated Decision Making and supervisory control.

Nonetheless, navigation at sea is not simply a computational challenge. The masters frequently face critical decisions that push them to the limits of safety, sometimes crossing those limits because of reasons not directly related to navigation. The issue of ethical decision-making was discussed by Moore (Moore, 2000), suggesting that it should be part of the masters education programs. More recently, following the accident of the cruise vessel Costa Concordia, several media reports questioned the existence of some code of conduct in the shipmaster community (Pawlik & Wittig, 2012). Such a written code does not exist. However, those concerns within the professional community and society came at the right time, since the principles of a such code should balance ship-owners' goals with the captain's responsibilities towards environmental issues or human lives. Some may think that the use of unmanned vessels will solve this problem, but ethics might be the main motive to justify the continuity of some kind of traditional ship captain.

Alterations in navigation tasks are stressed by the huge amount of data and information provided by on-board sensors, databases and shore based maritime services, leading to rising apprehensions about the workload and its effects on situation awareness and decision making (Endsley & Kaber, 1999; Hicks, Durbin, Morris, & Davis, 2014; Kaber & Endsley, 2003; Woods, Patterson, Roth, & Christoffersen, 2002). Bainbridge (1983) identified several automation glitches, such as over reliance, trust and feedback in human-machine collaborations, and drop of human's motivation and skills when engaged in monitoring tasks. The relevance of automation feedback and representations of ship's behaviour was highlighted in a study based on the grounding of the *Royal Majesty* (Lützhöft & Dekker, 2002). The same study points out the need for changes in the information systems to present new forms of highlighting changes and events, supporting the anticipation of changes, and facilitating the cognitive work involved in searching and scanning the displays.

Maritime navigation turned out to be a very complex and large-scale socio-technical system comprising human and man-made entities that interact with each other and operate in a rough environment (Mansson et al., 2016; Perrow, 1984; Vicente, 2004). Improving the maritime navigation performance requires the understanding of how the process works and its context. Therefore, we should address this problem as a joint human-technological activity (Hollnagel & Woods, 2005; Woods et al., 2002) or as "system of person-in-interaction-with-technology" (Hutchins, 1995). Some challenges were identified by Klein *et al.* (2004) for the success of human-agent team activities, comprising issues like mutual predictability, common ground, visible status and intentions, attention management, collaboration and negotiation. The thinking, computation and the decision-making processes are no longer only dependent of the operator himself but are also socially distributed among the elements of the team. These processes are made by individuals and cognitive tools available in Socio-technical Systems (Hutchins, 1995).

To develop a collaborative spatial decision-making tool, Antunes *et al.* (2010) overviewed several decision models to derive six different requirements: the support of perception, retention, knowledge externalization, divergent/convergent activities, recognition and task/pattern management. The collaborative view of this human-technological system leads to the assumption of an *ecological* design perspective (Flach, Vicente, Tanabe, Monta, & Rasmussen, 1998; Rasmussen & Vicente, 1989; Vicente & Rasmussen, 1992), where navigation functions are directed by the contextualized joint human-automated system, in contrast to the traditional navigator egocentric design.

2.4 e-Navigation

According to the e-navigation strategy (IMO MSC, 2009, p. 180), eight key elements were set, based on user needs: Architecture, Human Element, Conventions and Standards, Position Fixing, Communication Technology and Information Systems, Electronic Navigational Charts, Equipment Standardization, and Scalability. The Human Element needs more attention across all the maritime stakeholders, as it must consider several aspects, such as: training, competency, language skills, workload, motivation, alert management, information overload, ergonomics, and usability. IMO anticipates that ships shall profit from system and sensors integration, standardization of user interfaces, and a comprehensive alarm system. The central element of this system shall be the active engagement of the mariner in the navigation process loop (IMO MSC, 2009, p. 174).

The recently formed Sub-Committee on Navigation, Communications and Search and Rescue, from IMO, proposed an e-navigation Strategy Implementation Plan (SIP), setting up a list of tasks and specific timelines for the implementation of prioritized e-navigation solutions during the period 2015-2019 (IMO NCSR, 2014). Two of the solutions, solution S1 (improved, harmonized and user-friendly bridge design), and solution S3 (improved reliability, resilience and integrity of bridge equipment and navigation information), endorse the workable and practical use of information and data onboard.

Over the last decade, maritime stakeholders have had many debates over the e-navigation concept and the development of its implementation framework. All over the world, several research projects are bringing valuable contributions to the consolidation of this conceptual vision. At the same time developments in navigation and communication technologies are still evolving at a growing rate. Nowadays as automated systems are flooding ship bridges with information, mariners and industry are demanding more system integration and harmonized standards. However, as previously noted, complexity is increasing, not only onboard but also ashore, and most of the identified problems that are human factor related are still present.

2.5 Safety in navigation

Over the last decades, we have seen the introduction of new technologies in bridges, such as marine radar with Automatic Radar Plotting Aid (ARPA) capability, AIS, ECDIS, Integrated Navigation Systems, IBS, BNWS and other decision support tools. Additionally, many and everchanging regulatory frameworks, such as STCW, SOLAS, COLREG conventions and other safety management systems have been introduced. Even though they were implemented to increase navigational safety, they have also supported the enhancement of the overall efficiency and productivity. The focus on efficiency and productivity led however to a neutralization of their initial safety goals, inducing new types incidents and accidents (Kataria & Praetorius, 2014; Perrow, 1984). On the other hand, the impact of current CRM training on safety is still not clear, since more studies are required to sustain its claim to enhance safety (Salas et al., 2006).

It is now largely recognized that there are multiple factors correlated with the origin of accidents in complex systems. Usually it is their joint influence that triggers the accident. Several human factors have been identified in the maritime safety domain, such as: fatigue, automation, situation awareness, mental workload, communication, decision making, human–machine interaction, team work, organizational failure, health and stress (Chauvin, 2011; Grech et al., 2008; Hetherington et al., 2006; Schröder-Hinrichs, Hollnagel, Baldauf, Hofmann, & Kataria, 2013).

Along with the problems of standardization and self-regulation in high risk systems, described by Le Coze (2017), Psaraftis (2002) argued that the vast array of stakeholders involved in maritime safety policy encourages situations like over-regulation, overlaps, inconsistencies and gaps in the regulatory framework.

By studying the crew's perspective of maritime safety, Praetorius and Lutzhoft (2011) concluded that safety is supported by the capability of Joint Cognitive System (JCS) to maintain control. Furthermore, it is considered that safety can also be an emergent property of the system based on the interaction of all the participating agents: operators and technologies.

Reason's (Reason, 1995, 2000) and Rasmussen's (1997) influence in the systemic and organisational perspective of safety in complex technological systems set the ground for the development of several accident analysis methodologies focused on human factors, such as the Human Factors Analysis and Classification System (HFACS) of Shappell & Wiegmann (Shappell & Wiegmann, 2000). The HFACS framework was later on adapted to the maritime domain (Akyuz & Celik, 2014; Celik & Er, 2007) and applied for the studies of occupational accidents in shipyards (Celik & Cebi, 2009), organisational factors in maritime accident investigation (Schröder-Hinrichs, Baldauf, & Ghirxi, 2011), and analysis of collisions at sea (Chauvin et al., 2013).

With the purpose of enhancing maritime safety, IMO proposed its own structured and systematic methodology – the Formal Safety Assessment (FSA) (IMO, 2002a, 2002b), yet with no reference to empirical data, or its systematic analysis (Mullai & Paulsson, 2011). The FSA comprises 5 steps to support the conception of new regulations, as illustrated in Figure 7. Psaraftis (2002) noted that this framework is difficult to apply and used randomly, in part due to the constraints surrounding the policy-making process. This framework for safety and risk assessment, inspired the development of a system approach for the assessment of e-navigation technologies (Hahn, 2014). It provides a modelling framework for processes, fault trees and generic hazard specification, including a physical world and maritime traffic simulation system.

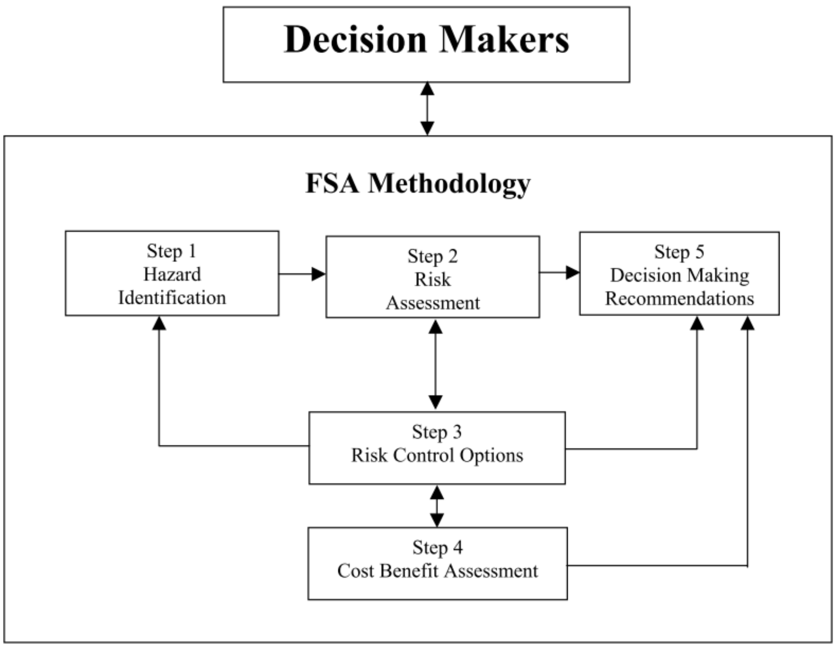

Figure 7 - Flow chart of the FSA methodology (IMO, 2002b).

Another systemic, however non-linear model, is Hollnagel's Functional Resonance Analysis Method (FRAM) (Hollnagel, 2007; Hollnagel, Hounsgaard, & Colligan, 2014) which characterizes socio-technical systems by the functions they perform rather than by trying to capture the causes and effects relationships. Consequently, it stands to provide a better understanding of the complexity and functioning of the socio-technical systems, and therefore a greater perception of how the factors interact and contribute to the origin of accidents. FRAM has been applied in empirical studies addressing navigational safety in the maritime Socio-technical System (de Vries, 2017; Praetorius, Hollnagel, & Dahlman, 2015), bringing detailed description of functions and potential success factors within complex Socio-technical Systems.

Grabowski *et al.* (2010) attempted the development of a framework that could present early warning information of adverse critical events, based on the assessment of safety culture and performance in maritime transportation. In their work, they identified significant correlation of safety factors with safety performance, namely: hiring quality people, safety orientation, promoting safety, a formal learning system, communication, problem identification, vessel feedback, empowerment, anonymous-reporting, and individual-feedback.

In two reviews of maritime accident models (Hetherington et al., 2006; Mullai & Paulsson, 2011), authors identified methodological issues with the research undertaken in the maritime safety domain. The problems where related with ecological validity of previous research, access to observation data, under-reporting of accident or incident data, large proportion of retrospective work, and the fact that several accident models are based on theories that may not take account of complex systems and phenomena. Schröder-Hinrichs *et al* (2011) also identified significant data gaps with regard to organizational factors.

Grounded on the concepts of resilience engineering (Hollnagel, Pariès, Woods, & Wreathall, 2011; Hollnagel, Woods, & Leveson, 2006) and safety II (Hollnagel, 2014), and through the investigation of IMO human factor regulations, Schröder-Hinrichs *et al.* (2013, 2015) discussed the need to change the traditional view of maritime safety. They argue that the improvements in maritime safety have been determined by reactive responses to adverse events, trying to remove the causes of vulnerabilities. In their view, a smooth shift is necessary to introduce the safety II approach, avoiding dramatic breakdowns in the current framework and keeping valuable instruments that are in place.

A new kind of safety thinking is required, placing humans as the source of diversity, insight, creativity, and wisdom about safety, not as sources of risk that undermine an otherwise safe system (Dekker, 2014). Thus, the design of the maritime navigation system must see the navigator as solution for enhanced control and safety cannot be only a bureaucratic process, but it has to be an ethical responsibility. Additionally, we have to leave the Cartesian-Newtonian view of linear cause-effect, and consider the complexity, unpredictability and variability of the interactions of the system components (Dekker, 2014; Taleb, 2010).

2.6 Modelling the navigator

The most widely used manuals of maritime navigation (Bowditch, 2002; UK Ministry of Defence (Navy), 2008), identify the key navigation tasks as: setting objectives, planning, execution, monitoring, and revising or adapting the plan. From a different view, Jul and Furnas (1997) proposed a navigator model which considers the following nonlinear tasks: setting a goal, selecting a strategy, collecting information, perception, assessing, creating a cognitive map and moving. The last four tasks represent the wayfinding/motion loop. Darken and Peterson (2001) defined wayfinding as the cognitive element of navigation, involving the formation of strategies and tactics that will guide the movements. The development and use of a cognitive map is an essential element of wayfinding. In this view, they consider navigation as the aggregate task of wayfinding and motion. Bjerva and Sigurjónsson (2016) proposed another concept of wayfinding and suggested that it comprises three steps: cognitive mapping, wayfinding plan development, and physical movement. Based on observations of pilots' mental workload, van Westrenen (1995) proposed a navigator model with a three-stage decision model, comprising tracking, short-term planning and long-term planning behaviour. In this view, long-term planning concerns mostly voyage planning, prior to sailing, and can be associated with the previous concept of goals setting and strategy selection. Short-term planning, comprises local observation and information collection necessary to make decisions over the control of the vessel. Tracking corresponds to the assessment of the movement and correlation with the initial plan. van Westrenen and Praetorius (2014) also suggest that each of these stages corresponds to three different types of control systems, used in diverse domains. Whereas strategical system refers to resource selection, tactical system is about the deployment of resources to provide capabilities, and control refers to the use of means to reach a desire state.

In the view of control theory, distributed control emerges from the increased interaction between agents. Distributed control supports self-organization and adaptability when facing uncertainty or unpredicted constraints (Flach, 2012; van Westrenen, 2004). Time and predictability are major determinants of such control systems (Hollnagel & Woods, 2005), thus in situations of low predictability and available time we will tend to find reactive decisions, where operators respond without having foreseen all the events.

In a different approach, Wolbers and Hegarty (2010) studied the interacting mechanisms that determine the individual's navigational abilities in cognitive and perceptual factors, neural information processing and variability in brain microstructure. They further suggested that spatial navigation involves sensory cues (environmental and self-motion), computational mechanisms (spatial computations and executive processes) and spatial representations (online and offline).

The conceptual navigation model adopted for this study may be visualized Figure 8a). It comprises three main functions: forming a goal, defining strategies and moving. Several nonlinear tasks are required in each stage and, all of them, have deliverables (goals, plan and control actions over ship). To support the categorization of visualization factors, the process of navigation is contextualized in the work space, Figure 8b), and available time, Figure 8c), together with expected control modes, Figure 8d), cognitive and decision-making processes, Figure 8e).

As an example, while sailing, the navigator tries to minimize reactive decisions (i.), as they are not thoroughly thought, they are usually linked to emergency situations and can only be well made thru experience and training. Since it is impossible to eliminate all the uncertainties, it might be worth to better prepare the ship for those events. Thus, a sound planning is the first mitigation measure (ii.), supported by cognitive processes that help to build a cognitive map of the physical voyage. At the same time, several alternatives are considered and tested. These processes will further support the perception and understanding of the real world (iii.), and control is based on planned responses or projected events.

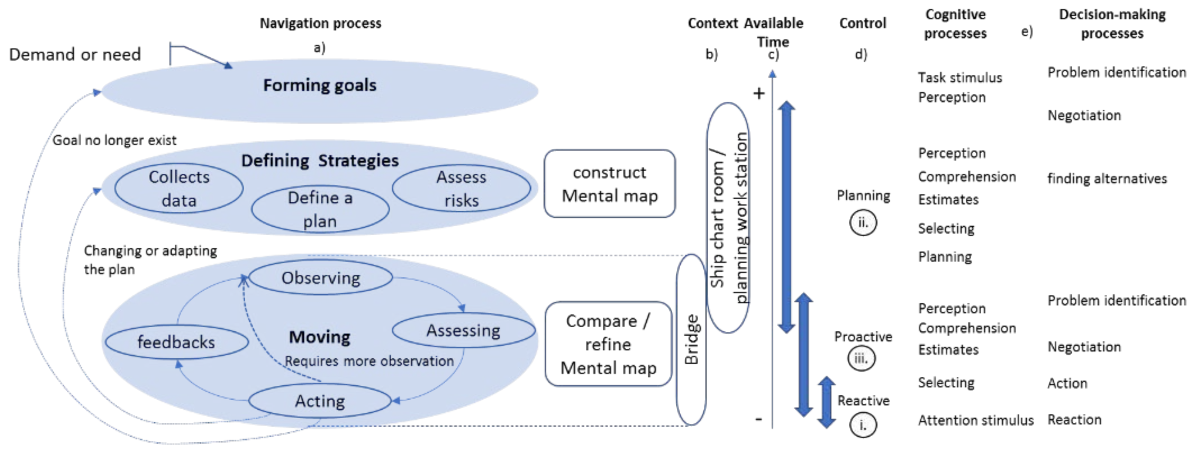

Figure 8 - Identifying the cognitive and decision-making processes within the navigation functions.

Information systems should be designed to support the identified cognitive and decision-making processes, considering the navigation function, context and available time. For instance, observing Figure 8, we can see that in the most front-end stage, when piloting the ship, events are occurring in the bridge and typical control modes are reactive and proactive. These control modes require continuous attention to stimulus and the operator must react in a short time. From this case, we may argue that by enhancing attention abilities we improve the reaction capabilities. We may also focus on higher stage processes, such as enhancing estimation and understanding cognitive processes, so the operator will use the proactive control mode, based on predictions that support better decisions.

3 Theoretical framework

The pursuit of more efficient and safer systems provided by increasingly complex technological systems, forced humans to constantly learn and adapt to new and unforeseen problems and shortcomings (Cilliers, 2002; Perry, Wears, & Cook, 2005; Woods & Dekker, 2000). Consequently, more important than blaming defective decisions or loss of Situation Awareness, is the understanding of how human factors are related to them (Dekker, 2014). We need to change the perspective of safety. Things go wrong due to latent failures of complex systems – system accidents (Dekker, 2011; Perrow, 1984), and rather than only pursuing accidents' causes we must address the success factors to deal with failures (Hollnagel, 2014). Hollnagel's ETTO Principle - Efficiency-Thoroughness Trade-Off, claims that we must consider both success and failure situations, since they are originated by the same reasons. However we should be focused on understanding why things didn't go right instead of why they did go wrong (Hollnagel, 2009).

3.1 System theory

Ehrenfels' celebrated thought "The whole is more than the sum of its parts", reflects the view of system thinking, where connectiveness, relationship and context becomes central elements. By 1940, biologist Ludwig von Bertalanffy (1950) formulated the framework of general system theory. Inspired from the biological sphere, he took the properties of holism, organicism, directiveness, and open systems, and revealed that they were shared by all kinds of natural and social complex systems (Bertalanffy, 1968). System elements are in mutual interaction, adapting and working together towards a purpose, which means they are goal-oriented or teleological (Bertalanffy, 1968; Skyttner, 2005). In open systems, the stabilization of the end state can be reached by different manners and initial states, varying the dynamics of the system.

Maintaining a stable characteristic or goal state requires feedback processes, working as a control mechanism for self-regulation and self-organization (Bertalanffy, 1968). These cybernetic concepts, were introduced by Wiener (Wiener, 1965) in 1948, while working on communication and control in complex system, especially in closed loops and networks. Bertalanffy (1968) pondered two levels of mechanism for system stabilization, one initially evolved from system dynamics regulation as an open system, and secondly the feedback mechanism that supports homeostasis and goal oriented behaviour. Cybernetic's feedback processes were later found useful in social system, such organizations (Wiener, 1965), looking for the understanding of work partition, communication between sub-systems, control systems and coordination toward organization goal (Skyttner, 2005).

General system theory goals include framing theories on system dynamics, goal-seeking behaviours and control processes. It also looks for the formulation of methodologies to explain the functioning of the system (Skyttner, 2005). Through synthesis, it aims to explain the properties or behaviour of an identified part or function of a system (Skyttner, 2005). System thinking brought a perceptual shift, focusing on the whole, looking at relationships between the parts, taking multidisciplinary and qualitative approaches, mapping patterns and processes (Capra & Luisi, 2014, p. 81). The essential elements of a system are the emergent properties found in patterns of the whole system and inexistent among the parts. If the relationships and interactions are destroyed the system properties are lost and the system fails.

The technological advances that nearly drown us in information, have also contributed to unforeseen changes in human and social behaviour, increasing the complexity by speeding adaptation and increasing connectedness. (Page, 2012; Vicente, 2004). Risk will never be eliminated from complex systems, due to their interactive complexity and tight coupling characteristics, reason why, when designing the systems, the strategies should be oriented in the view of managing the risk (Perrow, 1984). Hollnagel (2013) suggest that in tightly coupled systems, buffers and redundancies are part of the design, sequences are invariant and impossible to delay, with little slack opportunities. The demands of the Law of Requisite Variety (Ashby, 1958) challenges the design of systems that effectively control or manage complexity (i.e., that destroy variety) (Flach, 2012). Hierarchical, centralized control systems have severe limitations when coping with complexity (Flach, 2012). The way forward is to support the creative capacities of the humans, incorporate their wisdom, so we may provide the solutions in real time to problems that could not have been anticipated in advance (Flach, 2012; Page, 2012).

3.2 Joint activity

"A joint activity is defined as an activity carried out by an ensemble of people acting in coordination with each other" (Clark, 1996b, p. 3). Joint activity requires the existence of participants, roles, actions timing, commitments and a common ground of that activity (Clark, 1996a; Clark & Brennan, 1991). Klein and his colleagues, when generalizing these concepts to describe key aspects of team coordination, consider an activity as a "set of actions" (Klein et al., 2004) or a "set of behaviours" (Klein, Feltovich, Bradshaw, & Woods, 2005). From activity theory, Bedny and Harris (2005, p. 130) define activity as goal-directed system, where cognition (internal processes), behaviour (external processes), and motivation are integrated and organized by a mechanism of self-regulation toward achieving a conscious goal. The goal is the desired result or outcome of the activity and defines the object being manipulated and explored by the humans.

From the viewpoint of cultural-historical activity theory, an activity system comprises a minimum set of elements, including the object, subject, mediating artefacts, rules, community and division of labour (Engeström, Miettinen, & Punamäki-Gitai, 1999, p. 9). This framework, represented in Figure 9, offers a methodology to analyse human work in his contexts. It studies the interactions between the humans (subjects), the tools (mediating artefacts) being used and social shaping elements (rules, community and division of labour) (Cole & Engeström, 1993, p. 8). It considers two main types of activity, object-oriented and subject-oriented (also known as social interactions) (Bedny & Karwowski, 2004). Social interactions involve the understanding and comprehension of other subjects' activities and goals. The same goal may be commonly shared by different activities, but related activities from several levels may also support a more strategic goal.

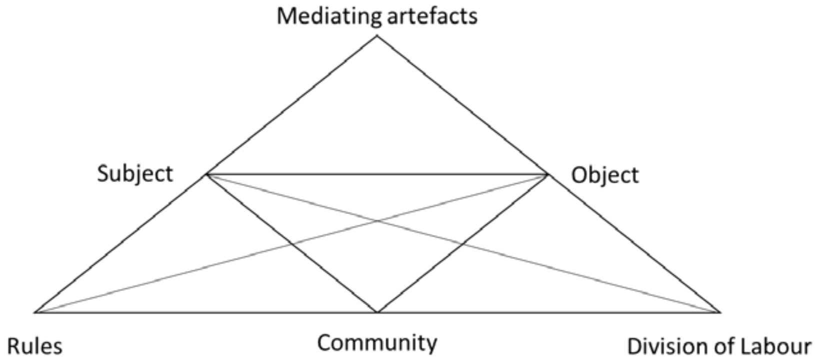

Figure 9 - Representation of the activity system as proposed by Engeström ((Cole & Engeström, 1993; 1987).

Hutchins (1995) claims that in the course of any activity, cognition exists within agents, being humans or artefacts, and is shared following a common goal (framework of distributed cognition). To understand cognition out of the mind, it is imperative to look to the ordinary environment and context where the actions occur. Rather than considering cognition as an internal process, it is seen as part of a stream of activities, distributed among multiple natural, artificial and cultural systems (Cole & Engeström, 1993; Hutchins, 1995; Klein, Orasanu, Calderwood, & Zsambok, 1993). Thus, distributed cognition turns to be an emergent property that arises from the interaction between people and their environment.

Figure 10 represents Klein, *et al*. (2005) view of joint activity through the articulation of three different elements necessary for the coordination of the activity: criteria, requirements and choreography.

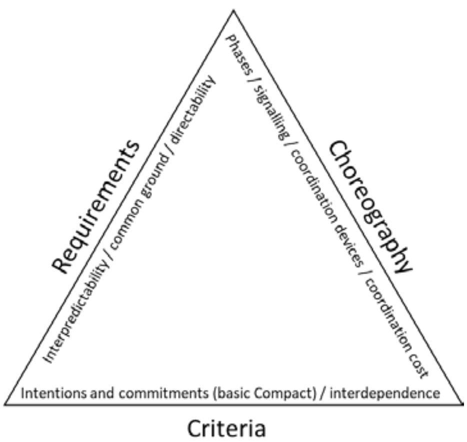

Figure 10 - Conceptual representation of Joint Activity. Adopted from (Klein et al., 2005).

According to Klein, *et al*. (2005), a joint activity must fulfil two primary criteria to be carried out successfully, firstly is the intention and commitment to take part of a joint activity, secondly is the interdependence of actions of the participants within the activity. When people engage in joint activity their individual motivations and goals must coherently align to support common goals, in short or longer terms. Thus, people need to enter into an agreement (often tacit), designated as Basic Compact, showing that they intend to work together.

All participants engaged in a Joint Activity must share the following requirements:

- Be mutually predictable in their actions. This mean that not only the participant must predict other parties' action, but he also must act in a way that it is straightforwardly understood by the others;
- Be mutually directable, aspect of coordination necessary to drive and adapt interdependences;
- Maintain common ground: mutual knowledge, mutual beliefs and mutual assumptions that support interdependent actions.

The choreography of a joint activity refers to the coordinated phases of joint actions, which may be planned and arranged with different levels of detail. Signalling represents participant interactions to share intentions, needs, difficulties or transitions between phases. Coordination devices are the mechanism used by the participants to signal each other. Finally, the coordination cost is the work and energy spent in the choreography, like the efforts spent in synchronization and signalling.

While studying joint human – automated system, Klein, *et al.* (2004) consider each control actor, human or nonhuman, as agents and identified the following challenges, that need to be addressed to consider them team players in a joint activity:

- Intelligent agents must fulfil the requirements of a Basic Compact to engage in common-grounding activities;
- Intelligent agents must be able to adequately model the other participants' intentions and actions regarding the joint activity's state and evolution;
- Human-agent team members must be mutually predictable;
- All agents must be directable;
- Agents must be able to make pertinent aspects of their status and intentions obvious to their teammates;
- Agents must be able to observe and interpret pertinent signals of status and intentions;
- Agents must be able to engage in goal negotiation;
- Support technologies for planning and autonomy must enable a collaborative approach;
- Agents must be able to participate in managing attention;
- All team members must help control the costs of coordinated activity

3.3 Socio-technical System

The ground for socio-technical thinking is that a successful system design requires the involvement of multiple disciplines, thus it should be a socio-technical process that takes into account the social as well as the technical factors that influence the functionality and usage of technological systems (Baxter & Sommerville, 2011; Norman, 2013). The increased performance of new systems can only be enhanced and work effectively, if the "social" and the "technical" are brought together and treated as interdependent aspects of a work system (Clegg, 2000).

In present dynamic conditions, the traditional top-down command-and-control approach deriving rules is no longer adequate, and it should be complemented with bottom-up initiatives to address the fast pace of technological change (Rasmussen, 1997). The interactions between the social or technical aspects embraces both linear "cause and effect" relationships and non-linear emergent relationships, with two relevant consequences (Hollnagel, 2013, p. 9):

> "The optimisation of system performance cannot be achieved by the optimisation of either aspect, social or technical, alone. Attempts to do so will increase the number of unpredictable or 'un-designed' relationships, some of which may be injurious to the system's performance.
>
> The safety of socio-technical systems can be neither analysed nor managed only by considering the system components and their failure probabilities."

Attention towards the focus on the people-technology relationship was raised, due to its influences on both human and societal needs and "Doing so should lead to a seamless integration of people and technology, eliminating the bad fits that are causing so much trouble" (Vicente, 2004, p. 45). This is what the socio-technical system model aims to achieve (Grech et al., 2008).

In complex Socio-technical System, transformation is a continuous process, human practice is altered by new technology and they in turn adapt the technology to suit new needs and requirements (Dekker, 2014, p. 229). Therefore, we should be cautious when aiming to model complex systems, they may help to give some insights and knowledge about the system, but it's impossible to figure out all its complexity (Cilliers, 2002). Thus, one crucial point is to understand how these transformations occur in context. Moreover, the design of new technology must be thought to enhance operator's awareness to unexpected and unimagined events and not only to provide delightful and comprehensive prediction of events (Vicente & Rasmussen, 1992; Weick & Sutcliffe, 2007, p. 47).

The concept of resilience has been most frequently described as successful adaptation in coping with adversity. Thus, resilience requires the presence of clear substantial risk or adversity. Socio-technical Systems that are concerned with failure can better detect the development of unexpected events (Dekker, 2014; Hollnagel et al., 2006; Weick & Sutcliffe, 2007). This is achieved by avoiding over simplification of details and being sensitive to the context of operations. Additionally, the containment of unwanted outcomes from unexpected event are made possible through resilient reactions and deference to expertise (Weick & Sutcliffe, 2007, p. 65).

3.4 Joint cognitive system

A Joint Cognitive System is composed by two or more systems, integrating people and technology, where at least one is a cognitive system. Based on Hollnagel & Woods' (2005, p. 20) Contextual Control Model (CoCoM), Potter *et al.* (2006, p. 314) define JCS as "the combination of human problem solver and automation/technologies which must act as co-agents to achieve goals and objectives in a complex work domain". The successfulness of the JCS function depends on the ability of humans and machines to work as coordinated team in the variety of complex work domains. JCS can result from the aggregation of other JCS from lower levels, where each level represent the system boundaries (Hollnagel & Woods, 2005, p. 113).

A Cognitive system can adapt its behaviour based on past experiences, and to meet the current and anticipated demands of the environment (Hollnagel & Woods, 2005). The aim of the joint cognitive system is to remain in control of its tasks and accomplish its goals. The functions that the JCS performs to reach these goals thereby become paramount, hence the relevant questions are to understand *what* a JCS does and *why*, rather than *how* it does it. Potter *et al.* (2006) consider that JCS must combine the following conditions:

- The entire set of humans, technology, and automation systems operate as one team;
- The whole system must be sensitive to the context in which it is currently operating;
- Changes in the level of autonomy affects the entire JCS and modifies the requirements of the automation with respect to interacting with the human;
- Decision-making must be considered from the JCS perspective (regardless of the agent making the decisions).

Cognitive System Engineering (CSE) focuses on the observable performance of these functions and on the variability of these functions in practice. The CSE perspective on automation is characterized by a view that the allocation of functions between people and machines should be designed to sustain and strengthen the joint system's ability to perform efficiently (Hollnagel & Woods, 2005). When addressing the potential performance variability of the JCS functions, potential risks to retaining control may be found (Hollnagel & Woods, 2005). The Law of Requisite Variety (Ashby, 1958) states that the variety of the systems' outcome can only be reduced by increasing the controller variability of that system. Therefore, effective control is only possible when the regulator variety is a greater than the system. Consequently, in the view of CSE it is fundamental to considerer the human as a controller (Hollnagel & Woods, 2005).

In a JCS, control is a function capable of directing and managing a set of events, which entails the ability to predict, respond to unforeseen disturbing events and effectively recover (Hollnagel & Woods, 2005, p. 136). While addressing unexpected or rapid series of events, there may be not enough time and resources to assess feedback signals or information. Hollnagel & Woods (2005, p. 137) suggest the use of feedforward control to act in cases of anticipated deviations. This mechanism of anticipation and enhanced readiness is strictly linked to the feedback control, which is based on the correlation of real-time observation and the predicted state. The Contextual Control Model (CoCoM), represented in Figure 11, reflects the influences of contextual factors over the preprogramed sequence of actions. Planning is a fundamental part of the control process, since it is sensitive to context and defines the required actions for the foreseen timeframe.

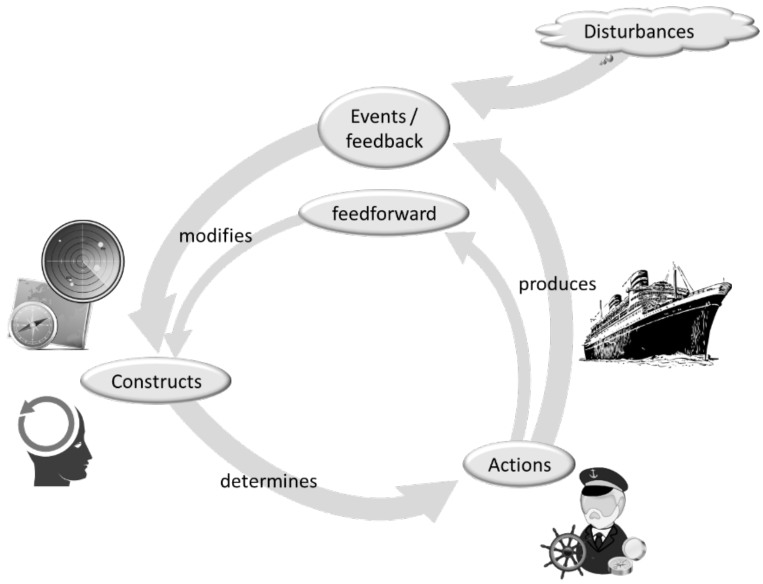

Figure 11 - The Contextual Control Model adapted from Hollnagel &Woods (2005).

To account for the variability in the degree of orderliness and regularity of performance, four different types of control modes are defined for the CoCoM: scrambled, opportunistic, tactical and strategic. In this sense, JCS performance is the integrated activities of feedback and feedforward control actions. Figure 11 shows how some characteristics varies between each control modes, where strategic controls are more effective in opposition to scramble controls. Hollnagel & Woods (2005, p. 75) also suggest four conditions that might impair the level of control of a JCS, in any domain: lack of time, lack of knowledge, lack of competence, and lack of resources.

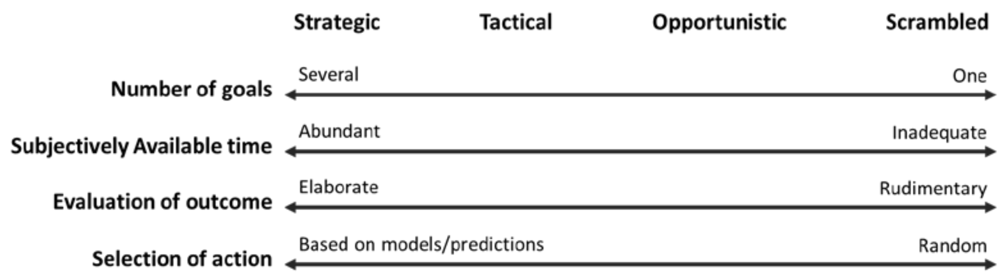

Figure 12 –Control modes properties in the CoCoM, adapted from Hollnagel &Woods (2005).

To account for diverse levels of performance that may simultaneously be found in a JCS, Hollnagel & Woods (2005, p. 149), proposed the Extended Control Model (ECOM), which embodies the dynamics between different basic control loops.

In Resilience Engineering (RE), systems are assessed in four different angles: monitoring, response, anticipation, and learning, which characterize the features a system should have to be able to maintain its functioning before, during and after predicted or unpredicted events have occurred (Hollnagel et al., 2006). On the other hand, high reliability organizations (HROs) are designed to strength their capacity to anticipate “unexpected” problems and to contain them through the adoption of five principles: preoccupation with small failures; reluctance to oversimplification; being sensitive to operations; maintaining capabilities for resilience and taking advantage of shifting locations of expertise (Weick & Sutcliffe, 2007).

Successfulness of JCS function depends on humans’ and machines’ ability to work as coordinated team in the variety of complex work domains. Four conditions might impair the level of control of a JCS in any domain (Hollnagel & Woods, 2005): lack of time, lack of knowledge, lack of competence, and lack of resources. In the maritime domain, safety is supported by capability of the JCS to maintain control. Besides, it is considered an emergent property of the system, based on the interaction of all the participating agents: operators and technologies (Praetorius & Lützhöft, 2011).

4 Research Methodology

4.1 Methodology approach

The understanding of how navigation is perceived and performed by the professional, in the present context, is an important question to set a new theoretical framework which could support the development of a model. The introduction of new technology, as perceived in the e-navigation strategy, requires a careful assessment methodology based on a mixed-method approach using focus groups, expert interviews and simulation-based exercises to determine the possible side-effects of changes to the overall system performance, as suggested in recent studies (Praetorius, Hollnagel, et al., 2015; Schröder-Hinrichs et al., 2015). Porathe and Shaw (Porathe & Shaw, 2012) also suggested methods to test e-navigation prototypes, in order ensure that such solutions would be profitable and would not prompt new problems. The proposed methods to work with user-centered-design were tested under the ACCSEAS project initiative and were summarized as: interviews and focus group, contextual inquiries / field studies, simulator studies, system simulation, user tests, and field tests. Another methodology to assess e-navigation information system, is to look at the available information that is not used and assess how it could improve the safety of navigation (Porathe, Lützhöft, & Praetorius, 2013).

To address the research goals, initial data have been collected from expert practitioners such as navigators, pilots and instructors. Trying to identify and collect everyday senses and experiences from current operations, guided the discovery and selection of relevant theoretical frameworks, which sustained the undertaken study. As proposed by Bedny, Seglin, & Meister (2000, p. 174) the analysis of the different tasks undertaken by the practitioners allows the assessment of the practices, strategies and arrangements used to solve the real problems.

Following the established research plan, the work has been focused on the following three levels:

- Grounded theory study (paper I): to understand how navigation is done and to perceive the sharp end view about maritime navigation. The work also contributes to the development of the contextual framework, establishing the interaction of the maritime stakeholder's interest and motivations around the maritime navigation system.
- Visual representations review (paper II): to understand the interaction between humans and technological interfaces. The study was oriented to the most common information system, which are visual displays. The research aims the evaluation of some specific system design concept that will be derived in conjunction with the complementary work (papers I and III).
- Non-Technical Skill research (paper III): to understand how these skills support navigation functions and to identify the relevant soft skills required for the new role of human agents. Additional concern was to understand how they might be developed, measured and monitored in a JCS. This study also provides valuable insights over the training needs and identification of new strategies to be applied in Maritime Education and Training (MET).

Models were built to facilitate the integration and analysis of the results, namely to support the explanation of scenarios or to clarify some processes based on the data, as suggested by Epstein (Epstein, 2008). The construction of models provides the tools to explore several themes, like dynamics, trade-offs, boundaries, thresholds, uncertainties, complexity and discovering new questions. The next diagram presents the system approach used to tackle three different views of maritime navigation, linking different perspectives over the common problem.

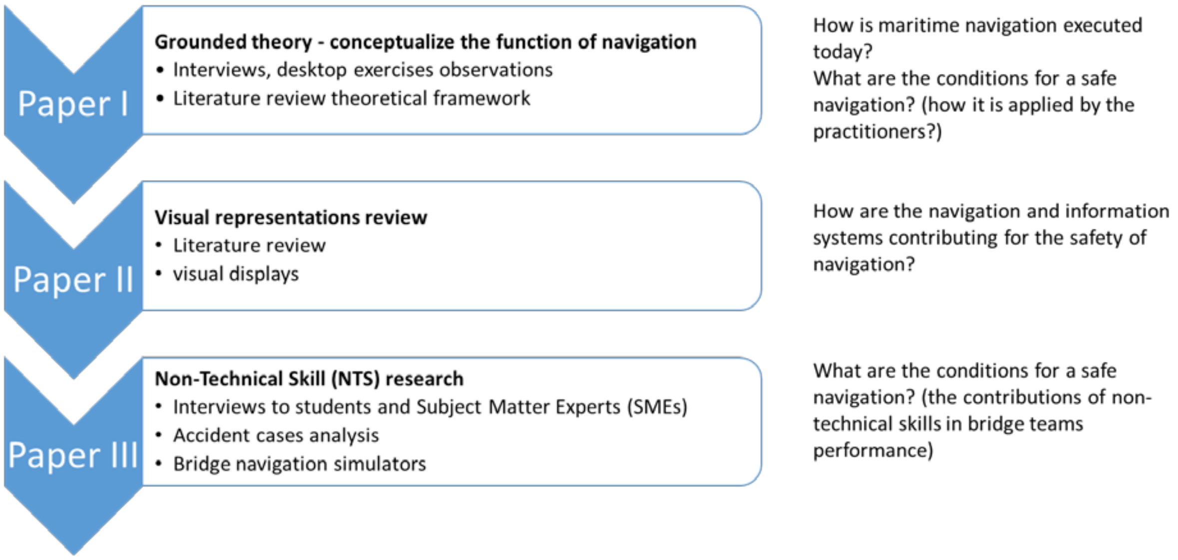

Figure 13 - Research methodology connection to the research questions.

4.2 Methodology paper I

To address the research goal, an exploratory sequential mixed approach was adopted, inspired on the Grounded Theory methodology (Charmaz, 2006; Creswell, 2014), starting with the current qualitative research phase to explore experts views and theoretical frameworks. The appraisal of the qualitative data and creation of the abstract model entails a system thinking approach, constantly questioning what the variables are, how the process is done and why it is needed? In addition, exploring the complex Socio technical System also requires the assessment of major trends, cross-scale developments and identification of emergent properties (Patton, 2011). Despite the general assumption that literature reviews should be done or consolidated after the grounded theory research, it is also recognized that it should support the categories' analysis work (Charmaz, 2006; Glaser & Strauss, 1967). Consequently, the adopted approach was to perform the open and axial coding process along with the literature reviews.

This first set of data directs the characterization of the bridge system, its functions and operations, in an outlined present time scenario. Data collection was performed through interviews and observation of Subject Matter Experts (SMEs) conducting desktop exercises. MSEs are people who know considerably more than others about a given domain of human knowledge, and approached by other who seek advices, instructions or solutions (Yates & Tschirhart in Ericsson, Charness, Feltovitch, & Hoffman, 2006, p. 433; Nichols, 2017, p. 22). However, for this study, SMEs need to be closely related to practitioners, since they are engaged in solving everyday problems in the field. Knowledge elicitation from practitioners' expertise provides substantial understanding of real problems, working constraints and strategies used when taking decisions (Wilson & Corlett, 2005). Classification of SMEs can be based on variables like experience in practicing as specialist or degree of skills associated with their performance (Meister, 2004, p. 101).

The selection criteria for a SME were: trained navigators within their respective work, with more than two years of recent active practice. The SME selection process reflected the requirement of congruousness representation of organizations whose operations characteristics contemplate the various types of navigation techniques and vessels. SMEs were found initially by contacting the organizations for suitable SMEs, and secondly by asking the appointed SMEs for other suitable SMEs in a snowball process. The sampling representation is composed by a total of 15 interviews, all from Portugal except one from Sweden. All the interviews were made in the native language (Portuguese) except one, made in English. The participants came from the following groups (Figure 14): sea rescue services, coast guard, Navy, shipping and harbour pilots.

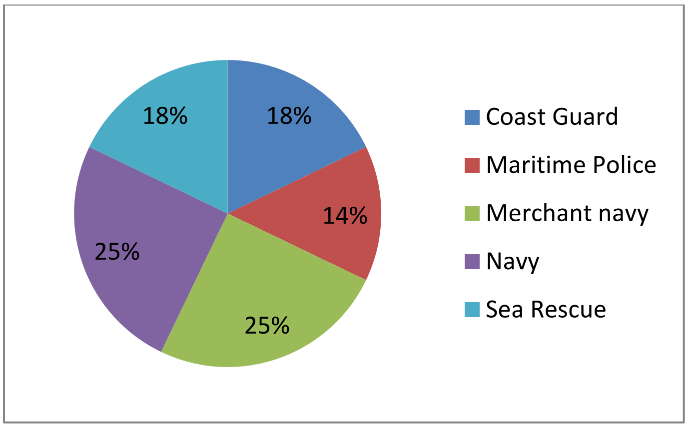

Figure 14 - Sampling distribution of the participants.

Participants represented different professional profiles, from captains to navigators, OOW and harbour pilots, with several years of experiences, as shown in Figure 15. They also characterise several types of operational activities, ship size, mostly performed in European regions (Figure 16).

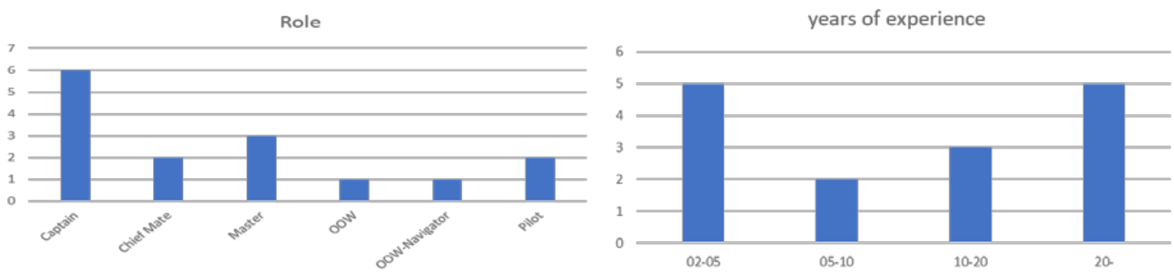

Figure 15 - Role and years of experiences of the SME.

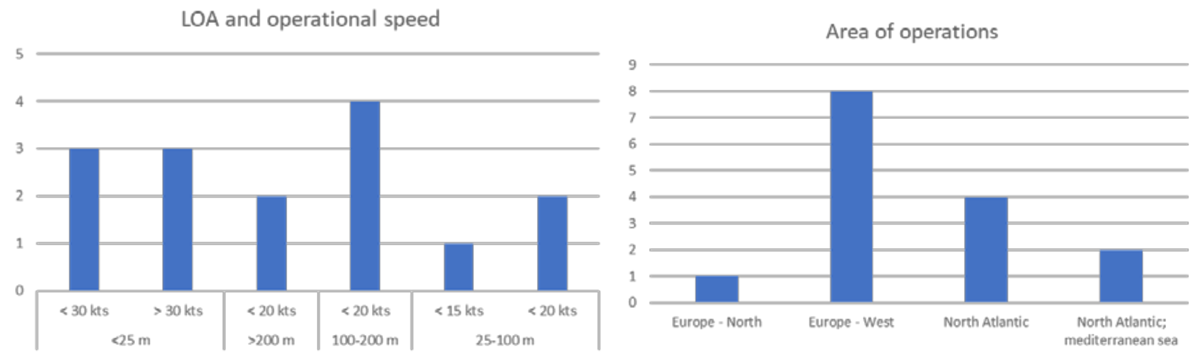

Figure 16 - Types of vessels and area of operations.

Fifteen semi-structured interviews with SMEs of thirteen vessels were conducted, with an average duration of 40 minutes per interview. The interviewer used a session guideline, containing 13 questions of interest. The responders were free to elaborate and in an open way express their views.

The interviews were followed by 3 desktop exercises (Figure 17), with an average duration of 15 minutes, where the SMEs were presented with a set of navigational situations that they had to solve and explain their line of thinking. The exercises covered the simulation of two coastal navigation scenarios and one in restriped waters, where the participants described and executed the planning work and how they would conduct the navigation. Throughout the observations, a think-aloud protocol was used to let the participants explain their actions and strategies.

Figure 17 - Desktop exercise.

The recorded interviews (audio and video) were transcribed, coded and analysed with Grounded Theory methodology, using QSR International's NVivo 11 qualitative data analysis Software. Prior to the interviews, the participant was informed about the study and gave their informed consent to record their answers. The interviews and the following coding process were performed by one researcher, also a navigator, with extensive experience from both large and smaller vessels. The interviews were conducted at places proposed by participant, 53% of them done within their working context (see Figure 18). Collected data was treated confidentially, published as synthesis or in terms of averages, ensuring that it could not disclose identifiable information about participants.

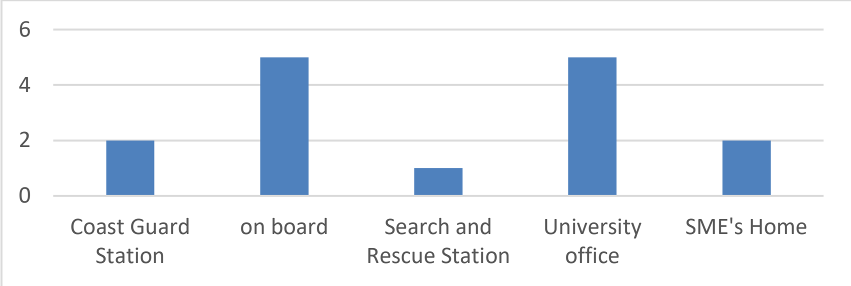

Figure 18 - Distribution of the interview's places.

4.3 Methodology paper II

The literature search performed in this review was conducted using several databases, namely SCOPUS, Science Direct, Springer Link, EBESCOhost and ResearchGate. The articles were selected based on their relevance to visualization in the navigation and orientation domains. In addition to these domains, other concepts related with operator's problems were combined, such as workload, attention and perception. Then, the following search terms were used: visualization, visual attention, visual perception, memory workload, cognitive workload, visual search, 3D visualization. Due to the large amount of results, additional keywords combinations were added as: wayfinding, navigation, orientation, map, decision-making, and situation awareness. Studies about eNavigation and related with these areas were also retrieved. Finally, a comprehensive search was performed in a selection of conference proceedings over the last 5 years.

The review applied a similar methodology as with Scoping reviews. Inclusion and exclusion criteria were driven by the criteria described in Table I.

Table I - Scooping review selection criteria.

ID	Criteria	Description
C1	Scientific Quality	accuracy, theoretical basis, with empirical data set
C2	Scientific Context	number of references to related work
C3	Significance	originality, applicability to maritime navigation, potential impact, vision
C4	Quality of Presentation	clarity, brevity, illustrations
C5	Qualifications	seniority and credibility of the authors and their institutions
C6	Studies addressing the following topics	Address human factors problems in visualization: attention, perception, information overload
		Measures of Effectiveness
		Visualization of uncertainty in data, visualize what is unknown
		Maps and georeferenced textual descriptions
		Strategies for visualizing [x,y,z,t] dimensions
		Studies applied in navigation and wayfinding
		Architectures for visualization systems
		Tools for collaborative visualization, visualization space as a workspace
C7	Published in English	
C8	Published in the recent years	focus on the last 10 years

A selection of previous reviews that address the focus of the review question was made, providing not only a synthesis of the research already undertaken, but also an initial guidance for this follow up review. Very few studies were conducted in the maritime domain, on other hand more were found in the field of air-based navigation. Apart from the above criteria, no review protocol was registered. The results were combined in the categories listed in Table II that were drawn from the navigation, cognitive and decision-making processes illustrated in Figure 8.

Table II - Categories and associated concepts used to guide the classification.

Cat ID	Category	Associated Concepts
CAT1	Visual Attention	Uncertainty, guided attention, visual search
CAT2	Visual Memory	Information overload
CAT3	Visual Perception	Strategies to predict and identify
CAT4	2D/3D	Space-time visualization, multi-attribute
CAT5	Wayfinding	Visualization in support of, strategies
CAT6	Planning	Creation mental map, learning, experience
CAT7	Multiple Task	Support of, collaborative decision process

The next table presents the correlation of the control levels and processes found in the navigator model and the adopted visualization classification scheme.

Table III - Correlation of Navigation control levels, processes and the selected categories.

Control level	Tasks and processes	Categories						
		1	2	3	4	5	6	7
Reactive	Observation, danger / hazards detection Attention Perception Situational Awareness Following procedures (plan) Distributed Control and cognition Experience / knowledge based	x	x	x	x			
Proactive	Observe patterns enhanced Situation Awareness by: previous assessments in plan forward planning, prediction estimations, computations, feeling… anticipates reactive strategies Manage and allocate capabilities Propose adjustments to plan Increases learning by assessing the predictions with what's happening Monitoring as an active task Distributed Control and cognition	x	x	x	x	x	x	x
Planning	Collects detailed information Estimations of information's changes Apply strategic purpose and norms Set targets to meet goal(s) Set boundaries (safety and performance) Set rules for proactive and reactive levels – SOPs (Joint activity common ground) Establish lines of actions and costs Shares internally and externally Cooperation	x			x		x	x

4.4 Methodology paper III

The proposed methodology aimed to develop a Non-Technical Skills (NTS) behaviour marking system, to be used in the navigation bridge simulator (NAVSIM) of the Portuguese Naval Academy. The framework's design considered a four-step process, sensitive to the navy needs and context. The first step was a compressive literature review to create a list of NTS that have been effectively studied in safety critical domain (Flin, O'Connor, & Crichton, 2008), such as maritime, aviation and health care, which would be useful for the OOW. This was followed by focus group questionnaires to NAVSIM instructors, aiming a better categorization of the NTS. The third step aimed at the contextualization of the Navy specific needs, done through the analysis of accidents reports involving Navy vessels and a second set of questionnaires involving NAVSIM trainees. The last step consisted in the qualitative analysis of the collected data and design of the NTS behaviour marking system.

4.4.1 Questionnaires

All questionnaires were completed over the first semester of 2016.

4.4.1.1 First questionnaire

A questionnaire was offered to lecturers and instructors who use or have recently used both NAVSIM, from the Naval Academy and the Tactical Training Centre, in training and teaching sessions, making a total of 10 participants. The questionnaire was composed by three parts. The first one covering demographic data including gender, age, years of experience and attended courses. The second part, aimed at the evaluation of the educational program in relation to the use of the NAVSIM and the characterization of the simulated sessions (9 questions). The last part focusing on the assessment of how the NTS are developed and which are considered the most relevant (24 questions).

4.4.1.2 Second questionnaire

Another questionnaire was directed to the student perceptions over the educational program around the use of the simulator. The questionnaire was presented to all students, except those from the 1st academic year, from all graduate degree program that use the NAVSIM, in total 139 participants, representing 90% of the population (see Table IV). The navy graduate degree programme (63% of the cadets) has more courses with modules conducted in the NAVSIM. This questionnaire consisted of three parts. The demographic part collecting age, gender, academic year and course pro-gram. The second part aimed at the evaluation of the educational program about their training as OOW (10 questions). The third part focusing on the development of their technical and non-technical skills in simulated training (22 questions).

Both questionnaires involved mostly close-end questions of multiple-choice and ordering. Seven open-ended questions were included, three for the students and four for the instructors. Before the implementation, a pre-test was performed on 3 individuals, to validate the adequacy of the questionnaires. The analysis was performed with the IBM® SPSS® Statistics for Windows, Version 20.0.

Table IV - Students participants.

	Academic year				Totals		
Graduate program	2^{nd}	3^{rd}	4^{th}	5^{th}		**N**	%
Naval administration (AN)	4	4	5	4	17	**17**	100%
Weapons, elect. Eng. (AEL)	5	2	3	3	13	**13**	100%
Mechanical Eng. (EMC)	7	6	3	5	21	**21**	100%
Marine (FZ)	0	0	2	1	3	**0**	0%
Navy (M)	28	28	24	18	98	**88**	90%
Total population	44	40	37	33	154	**139**	90%
Participants (N)	**42**	**33**	**35**	**29**		**139**	
	95%	83%	95%	88%		**90%**	

4.4.2 Accidents analysis

The analysis of the accidents was made using the HFACS-Coll framework proposed by Chauvin *et al.* (2013). The accident reports used in this analysis were obtained from investigation reports set up by the Portuguese Navy, on accidents involving Navy vessels. All navigation accidents were considered (in total 20 cases). They involved 8 collisions, 5 groundings and 7 collisions in mooring manoeuvres, from 1995 to 2016.

The coding process was separately carried out by two independent analysts, one of them an experienced mariner, using QSR International's NVivo 11 qualitative data analysis Software.

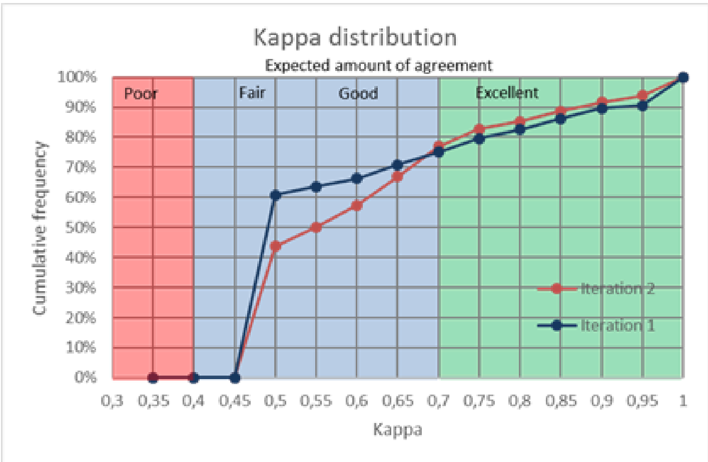

Figure 19 - Kappa distribution diagram of the coding process.

Two iterations were made, and the inter-rater reliability was assessed by measuring percentage agreements and Kappa coefficients. As it is shown in Figure 19, the second iteration significantly increased the degree of agreement. The adjustments of the HFACS framework were performed during the coding process, after discussions between the coders.

4.5 Limitations

This thesis attempts to present a new perspective on the marine navigation aboard a conceptual e-navigation bridge. However, at sea, mariners are sailing in a broad variety of vessels, ruled by several and different regulatory framework, conducting various types of operations, in very diverse contexts. Thus, to reduce the complexity of the unit of analysis of this research, in terms of dimension and interdependency between the different system components and functions, only the navy and SOLAS type of bridges will be addressed, leaving out other types of vessels, such as sailing vessels, leisure crafts and fishing vessels.

It's worth recognizing that the adoption of both Navy and SOLAS domains represents two different types of navigation methodologies and procedures. Not only manning in Navy vessels is substantially larger from what we find in SOLAS vessels, but also additional systems are available to fulfil different performance requirements.

The interviewer's professional experience and being known among the participants, may have introduced some bias in the interviews. It was felt by the interviewer, that the fact of being well known within the professional community as practitioner, lecturer and researcher, had made some influence over the subjects under observation, which could convey some bias in the responses and performances. In some situations, subject's behaviour and responses gave signs of trying to do what it is expected and not what it is done.

4.6 Ethical considerations

The thesis work focuses on maritime navigation, which is a high-risk system whereby unsuccessful adaptation may have major consequences. The main force motivating this study is the rapid evolution of technology to increase efficiency, production, and safety, which might create side effects, such as unintended complexities and increased practitioner workload and performance pressure. At the end, the results of the project will contribute to provide direction on how to improve the design of systems, including the introduction of new technology, training, and procedures.

By applying Grounded Theory, it is expected to extract the knowledge and theory from real life process, and portrayal concepts of collaboration and interaction between all the agents (people and technology) involved in the navigation process.

Despite the adopted measures to shield the identity of the participant and confidentiality of some cases, it seemed that the organization of their affiliation were also concerned about what the results could show. Therefore, formal permission forms were sent to some organizations to allow their employer to participate and get consent for publication in abstract form and statistical summaries. Integrity of the results still needs to be scrutinized through the presentation and discussion of the results with focus group of participants and others stakeholder's representatives.

Other sources of information are classified accident databases, namely from the Navy. Since security issues are involved, precautionary measures had to be considered to get permission for publishing the analysis and results.

5 Results

5.1 Results study I

Despite the initial purpose of the study, during the conduction of the interviews, new topics were added, such as the discussion over "safety" and "navigation safety". This dynamic development perspective provided a mean to describe and understand the active processes and their holistic effects on participant's activities. The new variables and schemes that emerged during the inquiry, which is a characteristic of naturalistic inquiry (Patton, 2002), provided a broader perspective over the research subject.

Some thoughts have been articulated, based on the analysis of respondent statements, related to the decision-making process, control strategies, and the relevance of planning. The existence of a plan and clear goals noticeably indicates dynamical variations in the navigation control arrangements.

SMEs had a common tendency to explain the tasks and procedures from the perspective of the artefacts, rather than the functions. For instance, by referring to the "RADAR operator" or by associating the RADAR to anti-collision. Moreover, operational procedures, that state the functions' performance, are largely hooked on technology standards. This hierarchical relation, places technologies as one of the main shaping force of the workplace and subsequently of the nature of the practice (Woods & Dekker, 2000).

Table V - Coding scheme.

Themes	Sub-themes and categories
Communications, connections	automatic communication, data link direct aural communication network radio aided or telephone communication taxonomy, semantics, expressions visual communication, mimics
complexity, complex	Complicated diversity dynamic, variable event proximity, short notice, low response time Uncertainty
Context	Area - coastal navigation Area - ocean navigation Area- close to land, shallow water Description of mission External - METOC conditions Current/ fog/ sea state/ tide/ visibility/ bad visibility/ normal visibility/ wind External - natural environment External - Night navigation External - operational environment density traffic, presence of other vessels /High risk operations/ towing Internal - the ship as all context - Ship characteristics context - Ship limitations Internal - working conditions/ work domain
Control	Adaptability automated control system Alarms centralized control constrained in the available options/ low freedom of movements

Themes	Sub-themes and categories
	distributed control feel in control flexibility High readiness manual control/ human No control/ control deficiency over confidence/ reliance Processes/ procedures readiness redundancy Regulations/ SOP/ norms/ doctrines tight/ caution/ careful control supervision Trust/ confidence feel in control flexibility High readiness manual control/ human No control/ control deficiency over confidence/ reliance Processes/ procedures readiness redundancy Regulations/ SOP/ norms/ doctrines tight/ caution/ careful control supervision Trust/ confidence

Decision making	Advisory
	comprehension understanding
	Goals
	information overload
	intuition
	Making sense. perception
	Mental model
	Planning
	    Forward planning
	    Re-plan
	predict/ forecasting
	    act as expected/ tradition
	    unpredicted
	reaction
	Sharing/ reporting
	Situational Awareness
	    assessment
	    Attention
	Veto

difficultness	concern/ preoccupation/ problem/ relevant/ important Difficult easy/ easier/ no problem fatigue/ stress Workload
Doubts & contradictions	
Effects/ consequences/ influences/ impact	
Information/ data	accuracy bathymetry chart information current error Human observation of external information (sounds/ wave directions/ celestial bodies/ land marks/...) information flow information updates integration METOC position variables/ factors/ indicators/ dimension
interactions	between team mates human–machine interaction Interaction with other vessels interaction with shore agency

Themes	Sub-themes and categories

Resource and subjects	Time
	    Task duration
	        time/ timing
	External
	    Tugs
	    VTS/ port control station
	Human
	    Captain
	    Harbour Pilot
	    lack of Human Resources
	    Pilotage team/ Navigation team
	        Navigator
	    Staff rotation
	    Team dimension
	        Small team
	    Team organization

Safety/ safely	Accident
	    collision
	    grounding
	creating problems/ increasing risk
	emergencies
	failure/ fault
	hazards/ dangers
	incident
	Individual Protective Equipment
	limits/ thresholds/ boundaries
	    safe distance
	    safe speed
	Risk

Seamanship	deck equipment operation emergencies manoeuvring Ship maintenance ships description special operations

Skills and competences	art of navigation
	communication
	Experience/ practice
	Expert/ specialist
	Knowledge
	Leadership
	learning
	    mentoring
	    on job learning
	motivation
	Technical competence/ education/ courses
	Training
	    inadequate training
	    insufficient training
	    simulation/ models

Stakeholders	maritime authorities own organization port authority

Task/ activity	Briefing
	coordination
	effectiveness
	efficiency
	Monitoring/ pay attention
	    continuous
	    lookout
	    periodic
	Task - pre-sail preparations/ checks
	Task - strategies/ practices
	Task example
	    great example
	team work/ Joint activity
	common ground

Tasks - Navigation	Anti-collision celestial navigation follow the plan geo-navigation

Themes	Sub-themes and categories

	position/ estimation
	positioning
	Speed
	    acceleration
	    Very high speed
	Steering & course
	    TRANSAS steering
	use of technologies/ artefacts
	    Aids to Navigation/ AtoN
	        buoys
	        Leading lines
	        RACON
	    calibration
	    AIS/ECDIS/Eco-sounder/GPS Plotter/GPS/ GNSS/Hand notes/ checklist/Magnetic Compass/ giro/Nautical applications/ software/Nautical Paper charts/Nautical publications/Navigation lights/Other Navigation Aids/RADAR/settings/ adjustments/VHF communications
	Voyage planning
	    information collection

5.2 Results study II

The results of the 24-selected sources, most of them published in journals (20), are summarized in Table VI. Publication years vary from 1980 to 2016, and the majority are from the field of psychology and cognition, with some from computer vision and cartography. The dominant methodological approach is experimental, together with four meta-analysis and few qualitative studies. Metrics are mostly associated with performance evaluation, measuring reaction times (RT), search times (ST) and target detection (TD). The analyst's familiarity with maritime navigation domain helped in the identification and interpretation of the relevant consequences of the findings presented in the literature review. It is acknowledged that not all the theoretical and relevant publications may be presented, however this selection provides sufficient ground to support the claim of new design requirements in the visualization of navigational information and decision support for navigation control.

The viewers' role in his perception of visual information depends critically on where his attention is focused and what is already in his mind prior to viewing an image (Healey & Enns, 2011). Additionally, human vision rapidly and automatically categorizes visual images into regions and properties (pre-attentive processing). Treisman's Feature Integration Theory (Treisman & Gelade, 1980), claims that if the target has a unique feature, one can simply access the given feature map to see if any activity is occurring, it also suggests that the level of difference between the target and the distractors will affect the search time.

The Guided search theory (Wolfe, 1994) suggest that an activation map based on both bottom-up and top-down information is constructed during visual search, meaning that attention is drawn to peaks in the activation map that represent areas in the image with the largest combination of bottom-up and top-down influence. Based on this findings, the bottom-up activation depends on feature categorizations, whereas the top-down activation is driven by the viewer's goals when looking to an image in search for the required visual information.

Boolean maps theory (Huang, Treisman, & Pashler, 2007) considers that visual search comprises two stages: selection and access. In this view, the visual system selects some elements of a scheme, excluding the others, and proceed for a deeper analysis by accessing additional details of the selected elements. Finally, the ensemble coding theory (Ariely, 2001) brings the idea that low-level vision can generate a quick summary of how simple visual features are distributed across the field of view. More recent experiments concluded that visual search of precisely known features are influenced by the presence of visually similar distractors due to limitations in selection and masking (Wyland & Vecera, 2016).

Table VI - Integrated summary of the selected publications.

Cit.	Year	Discipline, field	Methodology	Context
[28]	2012	Computer Vision & Pattern recognition	Meta-analysis	Attention and visual perception survey
[29]	1980	Psychology, cognition	Quant., 9 experiments Perfor. eval., ST + RT	Feature-integration theory hypothesis
[30]	1989	Psychology, cognition	Quant., 4 experiments accuracy of TD & RT	Efficiency of visual selection, T-N similarity and N-N similarity
[31]	1994	Psychology, cognition	Computer simulation, literature review	Model of visual search, Guided search
[32]	2007	Psychology, cognition	Quant., 2 experiments Perfor. evaluation	Boolean map hypothesis
[33]	2001	Psychology, cognition	Quant., 3 experiments Perfor. evaluation	Visual attention, circular spots of various sizes
[34]	2016	Psychology, cognition	Quant., 5 experiments Perfor. evaluation	Visual search for target object in cluttered scenes
[35]	2012	Cognition, Behaviour	Qualit., 1 experiments perfor. Obs. + gaze	Ground traffic control decision support system
[36]	2004	Psychology, cognition	Meta-analysis	Review of guiding attributes for deployment of visual attention
[37]	2007	Computer Vision & Pattern recognition	Meta-analysis	Visual attention, Taxonomy of Clutter Reduction
[38]	2008	Psychology, cognition	Quant., 1 experiments Perfor. evaluation, RT	Color and location in a visual search
[39]	2015	Cartography	Descriptive - Quant.	Map Viewer Design for Seniors
[40]	2012	Cartography	Quant., Modelling (computer science)	Map design, automatic symbolisation
[41]	2016	Cartography	Modelling (computer science)	Map design, distortion perception
[42]	2011	Visualization	Meta-analysis	Color use in visualization, survey
[43]	2010	Psychology, cognition	Quant., 3 experiments perfor. evaluation	Visual search of low prevalence targets
[44]	2013	Psychology, cognition	Quant., 2 experiments Perfor. evaluation	Cognitive load, multiple displays
[45]	2012	Computer Vision & Pattern recognition	Quant., 3 experiments perfor. simularion	Visual attention, feature type, layout impact on performance
[46]	2015	Computer Vision & Pattern recognition	Descriptive-Qualit., metho. Case Study	Decision-making, Uncertainty
[47]	2014	Computer Vision & Pattern recognition	Descriptive - Quant., questionaire + 1 exper.	Visual attention, Graphics analysis
[48]	2012	Cognition, Behaviour	Quant., Correlational Analyses	Visual perception, Spatial memory Persuasive Geocommunication
[49]	2016	Psychology, cognition	Quant., 2 experiments Perfor. evaluation	Visual attention, visual and semantic influences
[50]	2012	Psychology, cognition	Quant., 1 experiment perfor. simularion	Visual attention assessment in HUD, methodology
[51]	2003	Psychology, cognition	Quant., 1 experiment Perfor. evaluation, RT	Visual attention, mapping spatial attention

Top-down approaches to guide operators' visual attention have been tested by a model based on heuristic decision making, to foreseen user's decision strategies (Möhlenbrink, Manske, & Kirlik, 2012). Existing navigational information displays (e.g. ARPA, AIS, ECDIS) provide a large collection of features, each with several and distinctive visual properties (e.g. colour, orientation, size), resulting in a complex visual representation. Hence, we should simplify the visualizations regarding the users' task by minimizing visual confusion, this means for instance, adjusting the electronic charts symbols, depending on planning or monitoring tasks.

While planning, the navigator has time to assess all the chart features, to set the route and safe boundaries in accordance with his risk assessment. On the other hand, while monitoring, he is firstly concerned with avoiding hazards and to follow the planned route, which suggest that we have two major sets of information: dangers and positioning/navigation features. Therefore, features belonging to each of these sets should share a coherent visualization structure, that would evolve as the operator moves for additional search to find a detailed target.

Among several object attributes, colour, motion, orientation and size are strong guides for the deployment of attention (Wolfe & Horowitz, 2004). For many of them, the presence of a property is more readily detected than its absence, which might be relevant for the detection of moving targets (Wolfe & Horowitz, 2004). Additionally, visual search efficiency increases as a function of target–distractor difference and decreases as a function of distractor– distractor difference (Duncan & Humphreys, 1989). To address clutter in overcrowded displays, several mitigation strategies can be applied by manipulating the features' appearance, spatial distortion and animation (2007). The selection by colour in a multiple-item display, where location and colour information are independent from each other and equalized, is mediated by location information (2008). Yet, the attention of location seems to be equally influenced by colour and location cues. A study on maps colours, dark colours benefits the contrast of the map viewer content and elements, therefore improving the perception of the map contents. It also shown that long wavelengths colours shortens the viewer's reaction times in colour perception (Vrenko & Petrovič, 2015).

Visualization of real time multidimensional data generates complex representations, as it may be found in ARPA radar displays, and it is critically increased when combined with other information layers (AIS or ECDIS). New properties of the guidance cues can emerge from the deliberate or unintended combination of attributes, inducing positive or negative variations in the operators' visual attention. On the bridge, most of the available information is geo-referenced, and the trends confirm that more data is becoming easily available, such as aerial photos, textual information, routing and passage plans, weather and oceanographic data. Integration of this data demands further considerations over the cluttering effects. The combination of several distinct objects in the same presentation must be reassessed differently from the traditional selection of different layers, each with its own visualization properties. Automatic symbolization methods were developed to address the needs for layer's integrations minimizing any data loss (Sun, 2016; 2012) . All the features must be contextually and coherently merged to support and guide individual's visual attention. For instance, when supporting the perception of close situations, displays should provide a clear and prioritized view of all the hazards and dangers, blending features like depth contour, RADAR tracks and AIS information. Despite the different dimension of each feature, they are all hazards and this could drive the design of a common colour scales properties (Silva, Sousa Santos, & Madeira, 2011), to categorize their relative risk properties, e.g. time to closest danger.

One strategy to visualize large amount of information, has been using divided or several displays. This is more relevant when considering tasks involving search for low prevalence (LP) targets, i.e. that rarely occur. Low target prevalence alters the behaviour of the operator and the implication of these phenomena is the viewer's tendency to leave the search prematurely or to make motor or response errors. However it was found that no positive effect came by dividing up the display or by forcing the observer to slow down and correct errors (2010). In this view, it would be important to classify LP targets situations, like alarm cues, and study new designs to support their detection in time. Complementarily, it was demonstrated that simultaneous view is more appropriate than sequential view, further suggesting that the sequential view did not alleviate the divided attention problem, when we could suppose that sequential view would be more useful for monitoring tasks (Jun, Landry, & Salvendy, 2013). Viewers have a tendency to search for targets in novel locations in the display, as opposed to looking at locations that have already been examined (Healey & Enns, 2011). Therefore, we could infer that this phenomenon could determine the size of displays used by operators.

Attention limitation strongly affect the effectiveness of information visualizations, particularly the ability to detect unexpected information. Visual search experiments (Haroz & Whitney, 2012) revealed that search effectiveness can be increased by grouping, namely for oddball search, and reducing variety specially for demanding tasks. From these findings, we could again argue that same objects should be visualized differently depending on the user's task. It has profound implications in the way information is currently presented in bridge information's systems and subsequently in operator's effectiveness to extract information from them. Taking the example of ARPA displays, user's attention could be guided by grouping targets based on distinctive characteristics, like distance, CPA, TCPA or vessel type. Colour and flicker are attributes already used, but their effectiveness is reduced in congested displays, compelling operators to increase the RADAR scale and therefore losing the overall perspective. AIS data provides much more possibilities of manipulation due to the larger number of available dimensions, however the lowest integrity of this data recommends prudent evaluation of the integrated results, as they may cover-up erroneous data.

User's sense-making processes may induce cognitive biases in the process of visual perception, i.e., the type of representation may be subject to incorrect interpretations, particularly if the user is not familiar with the presented pattern (Ellis & Dix, 2015). Misinterpretations can emerge from clustering, completeness, anchoring and framing errors. One example that can be found on the bridge, is the representations of the same objects with different orientation schemes, such as AIS data in the ECDIS (north aligned) and in the radar display in head up mode. The mode error is found when the user unconsciously appropriates one of the visualisation schemas, due to its greater perceived authority, to another which unwittingly does not fit. In what concerns the effects of interpretation of missing graphical data, it was found that higher degree of decision-confidence was achieved with the combination of emptiness and explanation (Andreasson & Riveiro, 2014). Thus, rather than visualizing the last state or completing the data with some estimation form, it's better to provide a cue over the missing data. Additionally, map rhetorical styles influences the user trust in the data and confidence in answering questions about the data, which means that different rhetorical designs can help achieve different persuasive goals (Muehlenhaus, 2012). Moreover, it was demonstrated that visual attention is influenced by semantics, so among the visual qualifiers we need to ponder on the possible object meanings and how they might guide visual search (De Groot, Huettig, & Olivers, 2016).

Experiments have demonstrated that the locus of attention is symmetrically distributed around the viewer's point of fixation, leaving the peripheral area less observed (Hillebrand, Wahrenberg, & Manzey, 2012; Tse, Sheinberg, & Logothetis, 2003). On-board, when observing the ECDIS or RADAR displays, the focus of attention is usually the own vessel, therefore noting that user's attention is around that point, we should think in means to represent prioritized targets near that area, so they get a higher chance to be spotted. Moreover, viewers can resume an interrupted search much faster than they can start a new search, due to the unconscious perceptual predictions they make about the target based on the partial information acquired during the initial glimpse of a display (Healey & Enns, 2011). Additionally, based on the current display, users' domain knowledge may give expectations about where certain data might appear in future displays, improving viewer's ability to locate important data. Therefore, we should challenge the possibility to provide RADAR data representations with minimum necessity to change scales.

Base on the findings over the factors that influence the visual attention, namely the features attributes, information cluttering and colour scales, it becomes clear that current display standards should be revised, when it concerns integration of different systems, such as RADAR, electronic charts and AIS. They may not be dependent of the technology component but reviewed in the light of the supported task and the context of operations.

It is also clear that factors limiting the viewers' attention have serious implications in their ability to extract information from displays. Even the manipulation of commonly accepted pre-attentive attributes, like colour or motion, are not enough in heavy demanding cognitive task. Therefore, the arrangements of information displays should go in parallel with the review of the user's task, the focus shifts from the user to the function and how-to strength the interactions between these engaged agents (human or machine). Thus, it is not surprising that whenever we realise changes in the capability or performance of an agent, we should account for changes in his interactions with other agents, and consequently variations in the function performance.

Cognitive biases in the process of visual perception is a challenging human factor issue, these situations are strongly driven by top-down processes. Further research is needed in the development of mitigating solution to address the several errors that may rise in situation of visualization under uncertainty. This requires more empirical research such cognitive work analysis, and the provision of more flexible and adaptive working settings.

The greater understanding of visualization factors in visual attention and perception provides valuable contributions to the development of measurement of effectiveness indicators. This requires an integrated approach and empirical experiments that could deliver more insights over the advantages and influences of such indicators in the navigation function performance. Discovers over the visualizing missing data from Andreasson and Riveiro (2014), the scenes - recognition mechanisms explanation from Oliva and Torralba (2006), Neider and Zelinsky's (2011) studies of visual search in complex scene, and Fjukstad's *et al.* (2014) solution to deal with forecast uncertainty, all these studies gives valuable findings that could be applied in the development of new tools to measure effectiveness.

Several studies from different fields, have pointed at the importance of landmarks. They become determinant in the support of orientation and wayfinding, not only for the knowledge and interpretation in real world settings, but also for navigation in virtual environments. In the pursuit of appropriateness of the landmarks, it is necessary to conduct a systematic survey of those, providing accurate 3D representations and locations. Moreover, these findings challenge some currents views that landmarks and navigational marks have lost their use, due to the accuracy provided by the new positioning systems (i.e. GPS). Therefore, what we should consider is the development of new requirements for implementation of landmarks, in terms of location and physical attributes (size, colours, nomenclatures) by considering the new forms of navigation utilization in digital representation (2D, 3D, augmented reality and virtual reality).

Cumulatively, we should probably consider the development of new requirements for implementation of landmarks, in terms of location and physical attributes (size, colours, nomenclatures) by considering the new forms of navigation utilization in digital representation (2D, 3D, augmented reality and virtual reality). Research in Text Detection and Rectification in Real-world Images may also drive new guidance in the nomenclature standards of navigation aids, so they could simplify the extraction process.

Several issues derived from blending technologies on the bridge, ECDIS, RADAR, AIS, weather information, brought new problems were found in HMI, making theses system prone for accidents. These visualization problems strengthen the determination in the pursuit of new solution for maritime navigation. Digital data opens new possibilities, which means that we may certainly fuse the sensors data into single workstation, however new information representation is required, in a form that they are correctly design for the support of a well-known user task. For instance, chart and collision avoidance information should be coherently merged in the support of the different stage of vessel control (reactive, proactive and planning). The route exchange study, parts of the ACCSEAS and MONALISA project's e-Navigation, provided some concurrent insights to this conceptual view (Porathe, 2015; Porathe et al., 2015).

Map symbols appear to have a significant influence in the navigator orientation performance. Some studies are given new understanding on how they should be designed and applied. But, we have also seen that nautical charts are being merged with other georeferenced information, this means that new research is necessary to understand the combination effect of features and symbol designed for different purpose.

Some experiments have shown that 3D visualization can have some advantages in the support of navigation task. Additionally, we are seeing that human operators are using more and more technological artefact to interact with the real setting, from the navigating aiding system, passing by the 3D navigation chart system, to the augmented reality and remotely operating systems. This means that the designer must be open for different presentation perspectives of the navigational charts.

Finally, considering the most recent understanding over visualization issues, like visual attention, visual memory, pre-attentive processing; visual search, and the newest visualization technology, this review presents the bases to justify further researches to develop new forms of representation of navigational information (charts, weather, RADAR, AIS, texts) that could support the different control level. This means the provision of new information displays that best suits the demands for each control level, presented in section 1.1.

5.3 Results study III

5.3.1 Non-technical skills

The nontechnical skills (NTS) were mostly retrieved from other behavioural marker systems, the UT Behavioural Marker (Klampfer et al., 2001), NOTECHS (Flin et al., 2003), ANTS (Fletcher et al., 2004), NOTSS (Flin, Yule, Paterson-Brown, Rowley, & Maran, 2006), and NTSOD (Long, 2011), we also considered skills identified by Flin *et al.* (2008) and Devitt & Holford (Devitt & Holford, 2010). The literature review resulted in a list of 13 categories (see table 2), where a greater emphasis was found in skills like communication, leadership; situational awareness, decision-making and team work.

5.3.2 Lecturer survey

All the 10 participants, were navy officers, with an average of 6,5 years of experience in NAVSIM training, 90% male, two younger than 35 years and 4 older than 45, none with any documented simulator training education. The majority (80%) considered that the training in the NAVSIM could be improved. The participants use the NAVSIM for four different courses programs, as it can be seen in the Table VIITable VII - Course programs conducted in the NAVSIM.

Table VII - Course programs conducted in the NAVSIM.

Which course program do you manage?	**Y**	**N**
Tactical navigation / naval operations	6	2
Seamanship	3	5
Leadership / organizational behaviour	1	7
Navigation	7	1

Table VIII presents the NTS that were considered as the most relevant, by asking the participant to select five of the 13 categories of NTS.

Table VIII - Identification of the most relevant NTS.

NTS	**N**	**Order**
Decision making	9	1
Situational awareness	8	2
Leadership	6	3
Task planning and management	6	3
Monitoring, vigilance	6	3
Team work	5	4
Communication	5	4
Assertiveness	3	5
Managing stress	1	6
Perception, intuition	1	6
Coping with fatigue	1	6
Energy, mental alertness	0	12
Workload management	0	12

Two questions were directed for the understanding of methodologies used in simulated training, one to know which type of session is usually used and a second to identify the recommended type for the development of non-technical skills. Looking at the results in Table IX, we may see that the recommended type of session is the one that flavour a greater integration of the lecturer within the team activity.

Table IX - Configuration types for the simulated sessions in the NAVSIM.

Which type of session best suit the development of technical and NTS?	**0**	**1**	**2**	**3**	**4**	**5**	$\bar{x}$
Playing the scenario, with no interruption / instructor in the control room monitoring		6	1				1,1
Playing the scenario, with no interruption / active presence of the instructor in the bridge			1	2	1	3	3,9
Playing the scenario, with interruptions, for coaching and explanations of the instructor, in the bridge					3	4	4,6
Playing the scenario, with no interruption / active presence of the instructor in the control room				4	3		3,4

Note: (Y-yes, N-no / scale 0 to 5, where 0 stands for no answer, 1 for disagree and 5 for totally agree)

Table X presents the summary results of the lecturers' survey. While the first set of questions attempts to characterize the context of the training session, the second tries to gives us some understanding over the participant perception in the development of non-technical skills.

Table X - Instructors perception on the use of the NAVSIM as an educational tool.

	0	**1**	**2**	**3**	**4**	**5**	$\bar{x}$
Part II							
Are the number of instructors in NAVSIM session training enough?	2	1	2		4	1	3,3
What is the quality of the NAVSIM facilities?	2			1	6	1	4,0
Are the number of training sessions sufficient?	2			5	3	0	3,4
The total number of NAVSIM training hours for Navy graduate degree program is sufficient	4			5	1		3,2
The total number of NAVSIM training hours for Marine, Engineers and Administration graduate degree program is sufficient	6		3	1			2,3
Importance of long training sessions (> 12hours)	2	1	0	1	5	1	3,6
Part III							
Do you agree that training in NAVSIM is relevant for the development of both technical and NTS of the future OOW	2				4	4	4,5
How important is the development of NTS in the NAVSIM?				1	6	3	4,2
Do you perform briefings and debriefings?				2	4	4	4,2
Do you encourage OOW trainees to assign roles / tasks and clarify the responsibilities to the remaining members of their team?				1	4	5	4,4
Do you evaluate the trainees individually after each session?				2	6	2	4,0
Do you evaluate the trainees as a team after each session?				1	6	3	4,2
Do you encourage OOW trainees to monitor the tasks and sustain a common situation awareness within the team?				1	5	4	4,3
Do you encourage team work?	2				2	6	4,8
Do you encourage decision making in safety critical or uncomfortable situations?	2				7	1	4,1
Do you encourage the use of formal communication forms within the team?	2					8	5,0
Do you evaluate the radio communication procedures with other ships and shore stations?	2		1	0	3	4	4,3
Is the individual training session, preceded by planning work?	2			1	7		3,9
Is the group training session, preceded by planning work?	2		1	1	4	2	3,9
Just before the session, do brief the students with the session goals, plan and evaluation methodology?	1			1	4	4	4,3

	0	1	2	3	4	5	$\bar{x}$
Just after the session, do debrief the students with an analysis of the session, lessons learned and good practices?	1				3	6	4,7
Do you consider that NAVSIM training helps the development of leadership skills?	2				4	4	4,5
Do you encourage the OOW trainee to set priorities in accordance with the situations					3	7	4,7

Note: (scale 0 to 5, where 0 stands for no answer, 1 for disagree / never / very bad, and 5 for totally agree / always / very good)

5.3.3 Students survey

The participants of this survey, in total 139, representing 90% of the population, were all students of the Naval Academy, between 18 and 27 years old, 41.7% being between 21 and 22, 79% male. Further, 97,1% had already performed tasks in a bridge team, 92.8% considered that simulation training could be improved and almost half of them considered long-term sessions as a good way to increase their skills.

Three different tests were performed with the collected data, Kolmogorov-Smirnov, Kruskal-Wallis and Mann-Whitney. For a significance threshold of 0.05, Kolmogorov-Smirnov test shown that the data were not normally distributed.

Therefore, we choose to proceed with non-parametric tests. The results of the Kruskal-Wallis test gave high degree of significance in 7 over 13 questions for the Academics Years, and 9 over 13 questions for the graduate degree programs. When comparing academic years, the relevant questions are 8, 10, 11, 13, 14, 15 and 19. On the other hand, when comparing graduate programs, the relevant questions are 4, 5, 7, 9, 11, 13, 14, 15 and 21.

Table XI - Results of Kruskal-Wallis test for academic years.

p	.746	.313	.094	.009	.478	.000	.000	.001	.000	.000	.566	.088	.000	.740
Question	Q4	Q5	Q7	<u>Q8</u>	Q9	<u>Q10</u>	<u>Q11</u>	<u>Q13</u>	<u>Q14</u>	<u>Q15</u>	Q16	Q17	<u>Q19</u>	Q21

Table XII - Results of Kruskal-Wallis test for graduated programs.

p	.006	.001	.017	.119	.048	.179	.044	.043	.049	.000	.587	.154	.093	.028
Question	<u>Q4</u>	<u>Q5</u>	<u>Q7</u>	Q8	<u>Q9</u>	Q10	<u>Q11</u>	<u>Q13</u>	<u>Q14</u>	<u>Q15</u>	Q16	Q17	Q19	<u>Q21</u>

The next table presents the summary results of Mann-Whitney tests (multiple comparisons) made for the questions with high degree of significance.

Table XIII - Summary results of Mann-Whitney tests.

Part III		Academics Years	Graduate program
4	In NAVSIM, briefings and debriefings are carried out, by the trainees at the beginning and end of each training session?		M<AEL AN<AEL MEC< AEL
5	In NAVSIM, the instructors encourage OOW trainees to assign roles / tasks and clarify the responsibilities to the remaining members of their team?		M>MEC AN>MEC MEC< AEL

Part III		Academics Years	Graduate program
7	During the training sessions, in the NAVSIM, are you evaluated as a team?		M>MEC MEC< AEL
8	In NAVSIM, instructors encourage OOW trainees to monitor the tasks and sustain a common situation awareness within team?	$2^{nd} < 3^{rd}$ $2^{nd} < 4^{th}$	
9	During NAVSIM sessions, do the instructors promote teamwork?		M>MEC
10	During NAVSIM sessions, are you encouraged decision making in safety critical or uncomfortable situations?	$2^{nd} < 4^{th}$ $2^{nd} < 5^{th}$ $3^{rd} < 4^{th}$ $4^{th} > 5^{th}$	
11	In the training sessions, the instructor gives feedback assessment over the trainees' ability to assess situation?	$2^{nd} < 3^{rd}$ $2^{nd} < 4^{th}$ $2^{nd} < 5^{th}$ $3^{rd} < 4^{th}$ $4^{th} > 5^{th}$	M>MEC AN>MEC
13	Do the instructors insist on the use of formal communication forms within the team?	$2^{nd} < 3^{rd}$ $2^{nd} < 4^{th}$ $2^{nd} < 5^{th}$	M>MEC
14	Do the instructors evaluate the radio communication procedures with other ships and shore stations?	$2^{nd} < 4^{th}$ $2^{nd} < 5^{th}$ $3^{rd} < 4^{th}$ $3^{rd} < 5^{th}$	M>MEC AN>MEC
15	Is the group training session, preceded by planning work?	$2^{nd} < 3^{rd}$ $2^{nd} < 4^{th}$ $2^{nd} < 5^{th}$	M>MEC M> AEL AN>MEC
16	Just before the session, do the instructors brief the trainees with the session goals, plan and evaluation methodology?		
17	Just after the session, do the instructors debrief the trainees with an analysis of the session, lessons learned and good practices?		
19	Do you consider that NAVSIM training helps the development of your leadership skills?	$2^{nd} < 4^{th}$ $3^{rd} < 5^{th}$	
21	Do the instructors encourage OOW trainees to set priorities in accordance with the situations?		M>MEC

The results express a clear trend from the 2^{nd} to the 5^{th} years, namely regarding the increasing instructor's engagement to follow communication standards, providing team working instructions and decision-making in stressful situations. Differences were also found between the graduate programs, especially between the Navy graduates and graduates from the other programs. This could be connected to the fact that until the end of the 2^{nd} year they all attend the same courses, later they follow different curriculum, with the Navy graduates attending more courses and more demanding tasks in the SIMNAV sessions. This is also reflected in the instructor behaviour and, on the requirements, he/she sets for the trainees.

In general, more than half of the participants considers that they are motivated to manage tasks and to set responsibilities within the team.

Additionally, about 2/3 reported that they usually have briefings and debriefings of the sessions. 2/3 reports that the NAVSIM sessions helped them to develop their leadership skills. They consider that they are mostly evaluated as a team in the NAVSIM sessions rather than as individuals.

More than half report that the instructors encourage the monitoring tasks and support the development of situation awareness. While 60% feels that they are encouraging to work as a team, but surprisingly only 1/3 refers that they are encouraged to take decisions.

In relation to the type of sessions, their opinions aggress with the instructors, preferring sessions with interruptions, for coaching and explanations of the instructor, with him in the bridge. This was highlighted in the open-end questions, where they report that sessions were generally well planned but the instructors should be more time in the bridge, and they would like to have much more time in simulated training. When asked about the evaluation process, they referred that it should be more frequent and objective. 80% of the participants consider that the proficiency of the instructor is good or very good.

5.3.4 HFCAS of Navy accidents

Table XIV - Summary results of HFACS analysis (levels 1, 2 and 3).Table XIV present the results of the HFACS analysis, only showing the first 3 levels, that we considered to be more directly connected with the NTS. The causality factors with higher relevance are the decision and perceptual errors, non-use or misuse of instruments, Bridge Resource Management (BRM), inadequate leadership and inappropriate planning.

Table XIV - Summary results of HFACS analysis (levels 1, 2 and 3).

HFACS Factors	**N**	**%**
Unsafe acts	**20**	**100**
errors	20	100
Skill-based errors	11	55
Decision errors	15	75
Perceptual errors	17	85
Violations	9	45
Routine violations	2	10
Exceptional violations	8	40
Preconditions for unsafe acts	**20**	**100**
Environmental factors	20	100
Physical environment	14	70
Hydro-METOC phenomena	10	50
Visibility or lighting	5	25
Technological environment	17	85
Ship building-bridge design	2	10
Radar, ECDIS, NAVAIDS failure	6	30
Non-use or misuse of instruments	17	85
Conditions of operators	12	60
Adverse mental state	12	60
Affected SA	3	15
Attention deficit-workload	12	60
Complacency	1	5
Adverse physiological state (fatigue)	0	
Physical, mental limitations	0	
Personnel factors	19	95
SRM	19	95
Inter-ship communication	9	45
BRM	17	85
Ship-shore communications	2	10
Intra-ship communication	4	20
Unsafe leadership	**19**	**95**
Inadequate leadership	16	80
Planned inappropriate operations	15	75
Leadership violations	11	55
Failure to correct known problem	12	60

6 Discussions

6.1 How, at a deeper level, is maritime navigation executed today?

The following concepts embrace the system perspective: it is a system-centred design view, rather than human-centred design. Humans, technology and control systems are all considered as agents. The intelligence of the system depends on the level of interaction among their internal and external agents, such as vessels, Aid to Navigation or VTS. The rationality of the system is human based, and it is embedded in the governance of the system - centricity and unity. Yet, governance is a different concept than control. It means setting the purpose of the system and the common ground framework (top-down initiatives). All agents are aware of the goals and act in accordance with the context, their capabilities and other agent's behaviour. Agents are like nodes of the network that makes the maritime Socio-technical System, which could be human, automated or combined, depending on the scale that it is seen. Plurality and bottom-up initiatives enlarge the base for adaptability, since they allow more rapid and suitable actions when facing uncertainty or unpredictable changes in contexts.

The navigation plan is used to influence the decision-making processes in different levels, as it comprises the goal (what do we want?), the adopted strategies (how are we going to do it?) and the criteria (why?). It is not enough to have effective plans and goals: they must be shared and dynamically managed. This entails coordinate activities in two dimensions: one in the environment where the activity takes place, and a second one in the organizational domain where the activity is controlled. The scheme in Figure 20 represents the conceptual view of the dimensions with different levels of control.

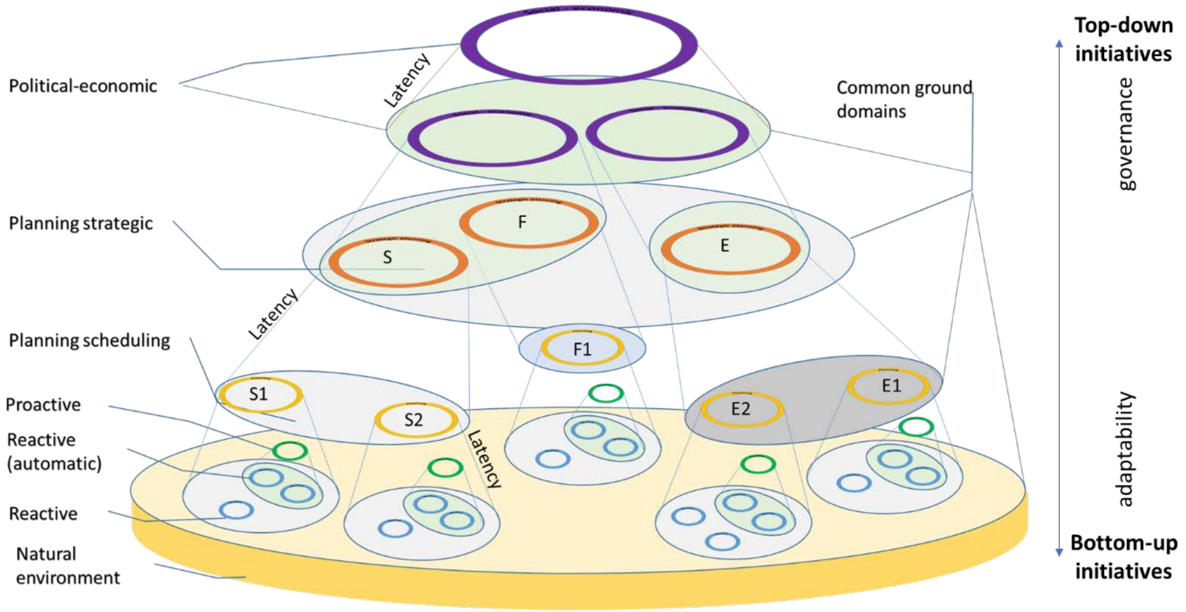

Figure 20 - Control levels in the maritime domain.

The contextual environments of the activities are in the horizontal planes, representing the common ground domain. The second dimension is represented by the vertical arrangements of the control levels. The lowest domain is in the natural environment, which is used by all actors, such as shipping (S1, S2), fishing (F1) or renewable energy (E1, E2). Regardless of the different purposes, they must interact and negotiate their safety boundaries. So, to support this interaction, a common ground must be settled. Actors with little commonalities are more prone for misunderstanding. For instance, wind generators are signalled with specific lights to help their detection and identification. Due to their height, they must also signal air navigation. However, light characteristics have different meanings for mariners and airplane pilots. The problem came when the floating devices where tilting, making visible lights that should not be visible, thus creating confusion. When new actors join the scene, unpredictable interactions arise. Klein *et al.*'s (2005) concept of common ground shall be considered in the two dimensions, one in the joint activity controlling the vessel, another one in sustaining the interaction with other actors sharing the same context.

The vertical dimension comprises 5 types of controls, further explained in next section, and drawn from the conceptual views of Rasmussen (1997), Hollnagel and Woods (2005) and Flach *et al.* (2013). The reactive control level responds to unexpected events or is triggered by automated action. The proactive control, supported by reactive controls, acts on the prediction of forward events based on real time observations. Both reactive and proactive controls are situated on the bridge. The planning control level acts when the ship is tasked, or a plan needs to be revised, and this corresponds to the ship captain's level. The next level is the strategic planning, which corresponds to the company level and acts in response to a social need. The last level is the political-economical control, comprising corporations, governments and international organizations, acting to harmonize the stakeholder interests and interactions.

The navigation plan contains various variables that drive all the control levels. Captains appraise routes, considering company's performance indicators, selecting the shortest route and economical speed. However, sustainability effects are also pondered, like emissions reductions with slower speed or accident mitigations. Moreover, plans are a mean to clearly set orders to the bridge team, since they include safety margins and methods of executions. As one captain said, he used the plan as a measure of effectiveness of the bridge team. However, it also allows dealing with uncertainty, since he sets safety limits to be managed by the bridge team and contingency plans. Therefore, the plan is a common cognitive map which is differently used by each control level of the JCS.

The dynamic control emerges from the perception of the purpose of each control level, each one managing specific variables. Captains set base courses, speeds, and safety limits. Bridge teams use proactive control, making necessary adjustments in face to the real-time observations and assessments. The top-level controls, give clear guidance on ethics and governance to rule the stakeholder interactions, such as goals for pollution reduction. The plan is also used to support the interaction with collaborative services, like VTS or pilots, revealing the perceptions and intentions of each actor (Mansson et al., 2016). Each level sets thresholds for the lower level. Yet, all variables are dynamically distributed and managed, supporting the adaptability of the JCS to the variation of each horizontal domain.

At the bridge, the cognitive map derived from the plan guides the attention and perception of the proactive control. This favoured control level depends on continuous observations, assessments and predictions. This process of appraisal and adjustment of the plan generates a learning process. However, it requires the active engagement of all agents, human or technological. This engagement foster the trust in automation, through a better understanding of the deviations, and by giving a perfectly reasonable common ground to interact with the system, comparable to what Klein *et al*. (2005) claim for the joint activities. This ultimately increases the JCS's knowledge and reduces uncertainty. On the other hand, when the plan is inappropriate or inexistent, there exists a larger engagement of the reactive control level, since the cognitive map can only be elaborated based on real time observation, demanding more resources and time.

The existence of a plan and clear goals noticeably indicates variations in the navigation control arrangements. It positively shapes the decision-making process, both reactive and proactive forms. Notwithstanding the conceivable presence of worthy plans and goals, they are not enough; they need to be shared and dynamically managed, which entails a resilient common ground. These common ground domains must embrace the context conditions and the system functions, whatever the dimension of the socio-technical system. This mean that system design considerations should take in account not only the internal interaction of the agents (human and technological) but also the external ones, acting closely at the same "ground" (horizontal dimension) or interfering at the managing level (vertical dimensions) (Figure 21).

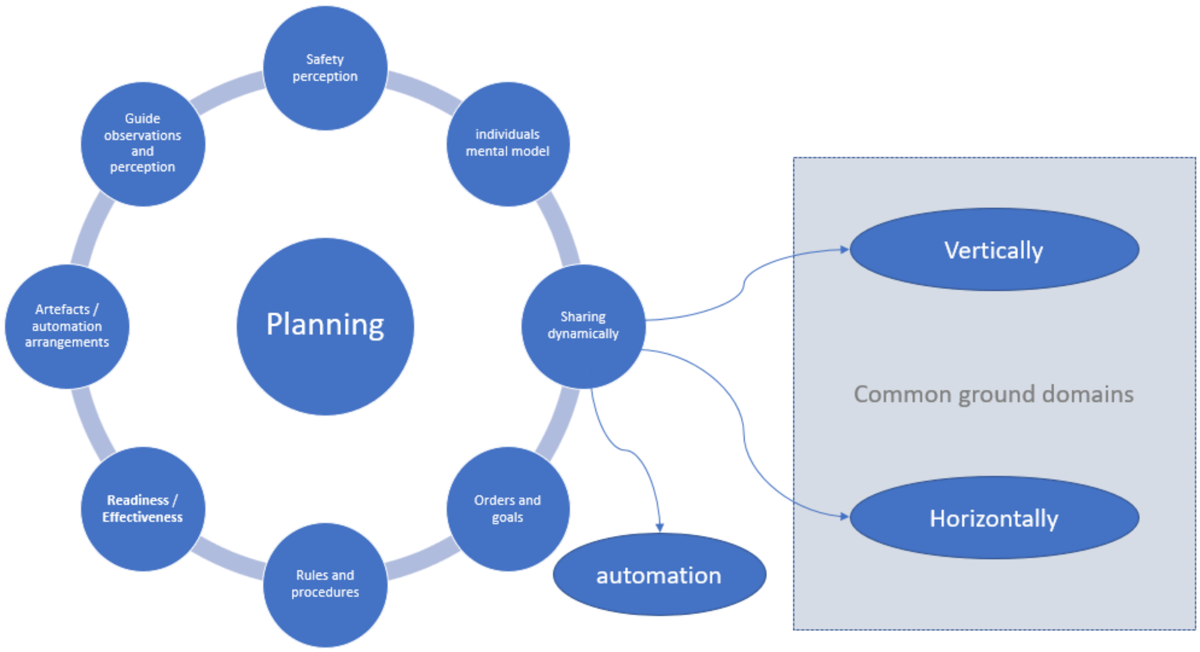

Figure 21 - Planning processes and the development of common ground domains.

With the representation of the dimensionalities of the several control levels, we conceive the domains of the interactions. Common ground is created on every horizontal domain, where stakeholders share the same context, and on the vertical dimension, to support the effectiveness of the control functions. This construction recognizes the importance of both bottom-up and top-down initiatives. The unpredictable property brought from complexity, along with the large impact of some of the unforeseen events, can only be faced by the sharp-end control. Therefore, their performance must be enhanced, by providing clear goals or effective management of the interactions.

This Grounded Theory research is showing that planning not only facilitates the interactions by enhancing the predictability of events, but also supports the distributed control. The latter is accomplished due to improved learning capability, trust and distributed Situational Awareness. When designing Socio-technical Systems, the technology and control system should behave as active agents and encourage the engagement of the human and their interactions. Developing an interpretive framework of maritime navigation is helping the identification and reasoning of the interactions that emerge within this complex Socio-technical Systems.

6.2 What are the conditions for safe navigation?

6.2.1 Navigation control

Safe navigation is achieved by JCS comprising by 5 control levels. In this conceptual model, the most singular element will be the reactive control level, which respond to a planned or unexpected event or because it makes sense. It works in the base of observations, attention, perception, procedures and plans, experience and knowledge. This control agent (human or technological) is in condition to influence an event by creating, generating, inventing or providing ad hoc solutions.

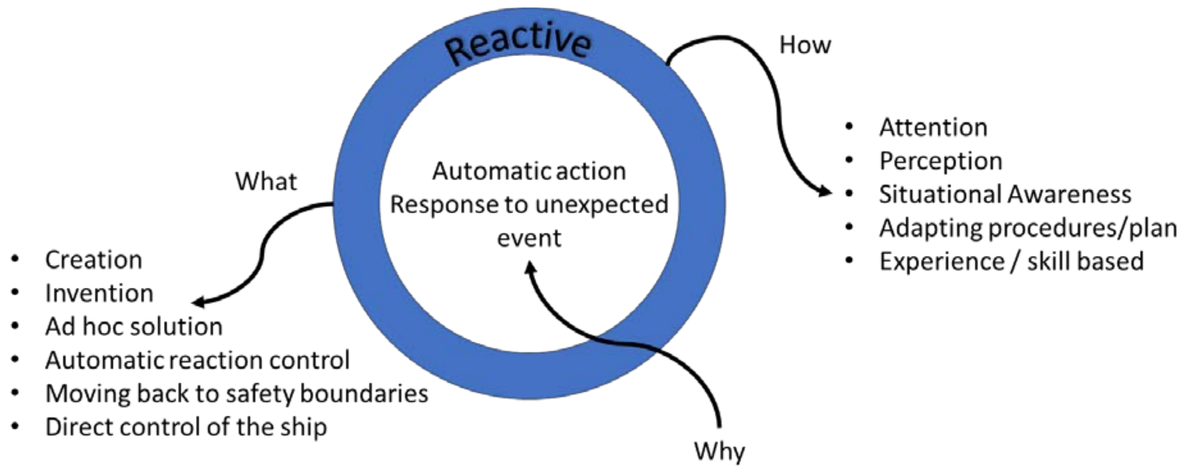

Figure 22- The reactive control level.

Another basic control element is the proactive control, which may be supported by reactive controls, and can predict forward contexts or anticipating disruptive situations. This enables some adjustments of the plan, in accordance with established procedures, existing goals.

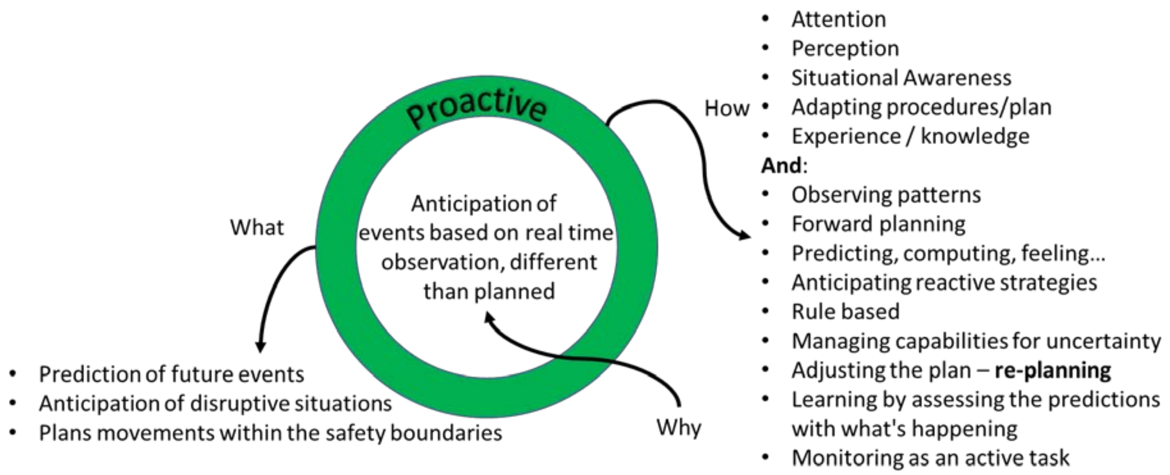

Figure 23 - The proactive control level.

In the maritime domain, the reactive and proactive controls are jointly parts of the bridge system. Above these basic controls element is the planning control level, which acts when a tasked or a plan need to be revised. What it does is to set a reference plan and manage the available resources in agreement with the established goals. This control can be considered as the command of the ship system.

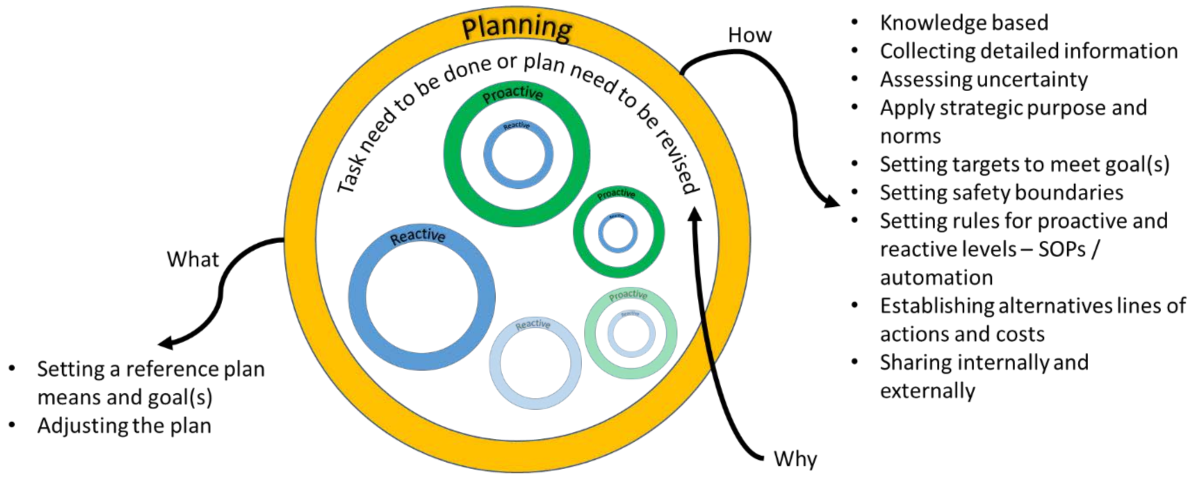

Figure 24 - The planning control level.

The next level is the strategic planning control, which have the function to respond to a social need or demand. It has the responsibility of governance, providing efficiency guidance for the lower levels, setting the purpose and tasking the planning control elements. This element represents the organizational dimension, which has a large responsibility in transposing the regulatory framework into procedures and norms, as well as providing the structure for the development and support of the ship's joint activity requirements.

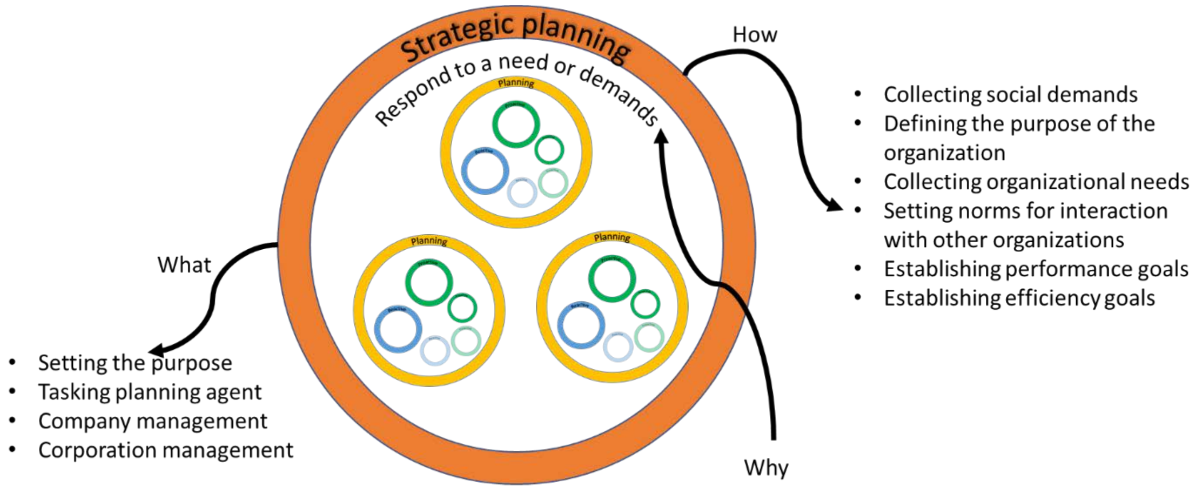

Figure 25 - The strategic planning control level.

To regulate the interaction among the several stakeholders, a central entity is necessary - the political control level, which has the function of global governance. This governance is reached throughout the agreement of general goals, with ethical and moral models that regulate the interaction between all the stakeholders (social and economic organizations or individuals).

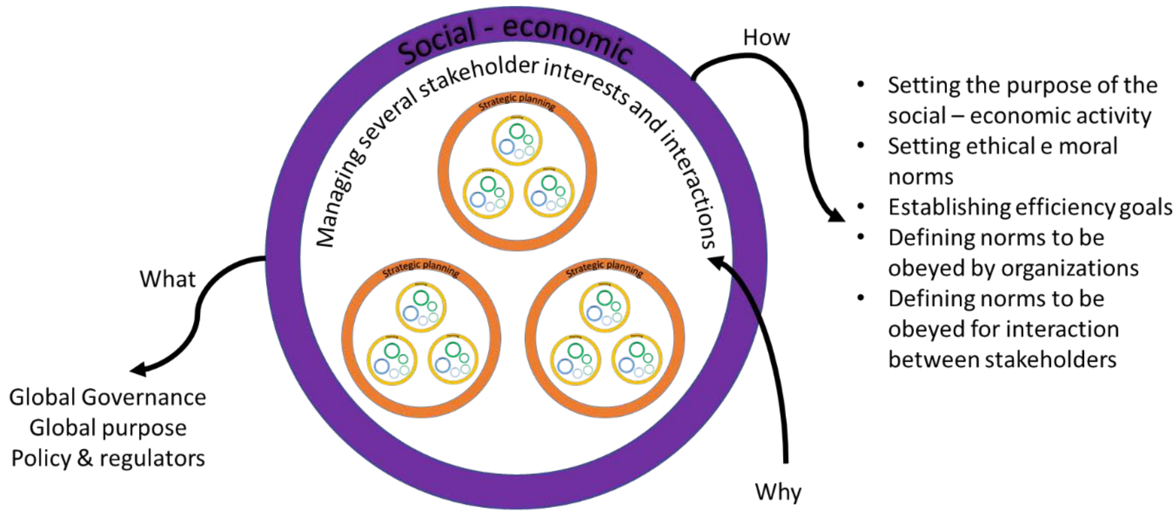

Figure 26 - The political control level.

Looking back at Figure 20 with the representation of the dimensionalities of the several control levels, we may conceive the domains of the interactions. Common ground must be shaped, not only for every domain, but also at across the horizontal level, where the several stakeholders share the same context, and over the vertical dimension to support the effectiveness of the control functions. From this construct, we recognize the importance of both bottom-up and top down initiatives.

In this structure, the terms strategic, tactical, and control are used; these have slightly different meanings in the various domains. Strategic meaning the selection of the means to achieve a goal, e.g. ordering tugs or waiting for the tide. Tactical meaning the deployment of the means to realise affordances, e.g. positioning the tugs or deciding to overtake. Control is about the use of the means to realise a desired state, e.g. realising a heading and speed

6.3 How can we improve ship navigation control for safe and efficient navigation?

6.3.1 Designing for safe navigation team work

In current times most of the technology that we find on the bridge is there to support the human or to replace him, as represented in Figure 27. The individual is “solely” engaged in:

- Setting parameters and plan
- Monitoring
- Respond to alarms
- “Assuming” the responsibility of the decisions

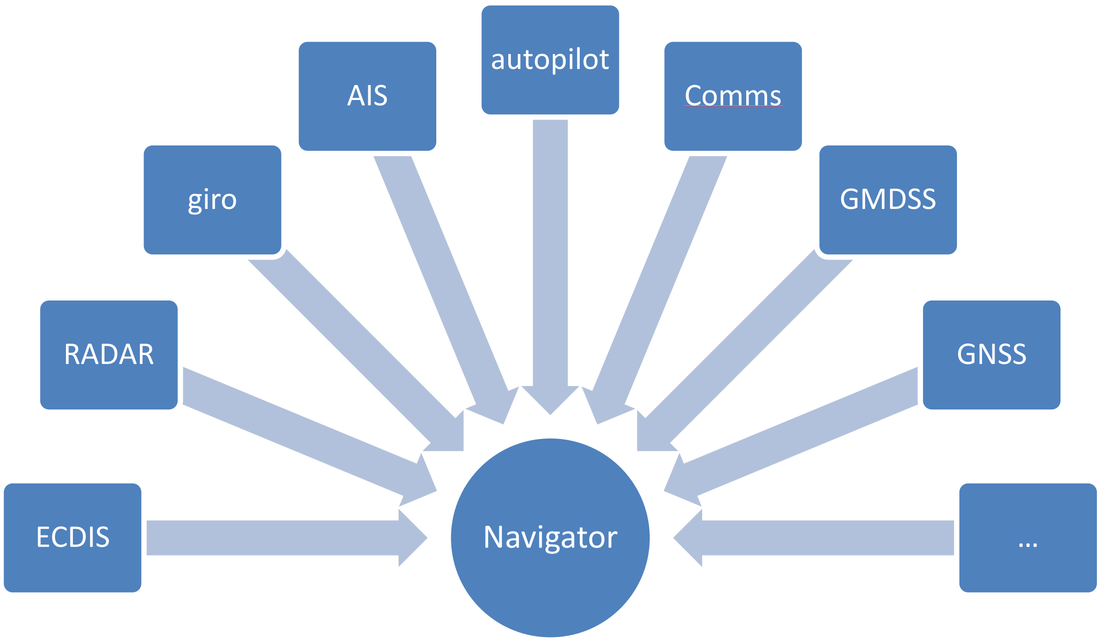

Figure 27 - Perspective of the current bridge system.

When designing Socio-technical System, the technology and control system should behave as active agents, encouraging the engagement of the human and their interactions. The concept of inverse navigation design is based on the idea that every automated agent should act intelligently, within its limits, and work as team elements in a joint activity. This concept, represented in Figure 28, embraces the system perspective, it’s anthropocentric and not egocentric, and it is a use-centered design view rather than human-centered design. Human, technology and control systems are all considered as agents. The intelligence of the system depends on the level of interaction between internal (existing in the ship) and external agents (vessels, AtoN, VTS, etc.).

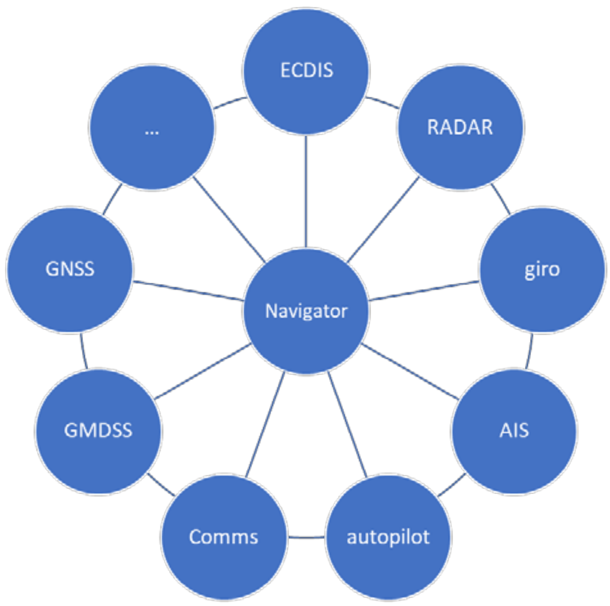

Figure 28 - System view of "inverse navigation design".

Adaptability emerges from the continuous processes that are supporting the planning function, which hold the integrity and coherence of the track keeping and hazard avoidance functions, previously shown in Figure 2.

So, how to design inverse navigation? The answer lies in swapping the monitor function role. Consequently, we should place the technology with the task of “asking” the human operator to verify system calculations, like:

- Measurements (bearings, star observation, distances, etc.);
- Identification of targets or land marks (type of vessels);
- Consistency of natural elements (wind, waves, visibility).

Distributed control should emerge from the increased interaction between agents, i.e. if no expected action is seen from an agent, others capable, will act in accordance with the system purpose (Sense making of agent’s behavior). For instance, if some failure appears in one of the equipment, it would affect the readiness of the ship, thus it should trigger some re-assessment of the safety boundaries. Adjustments in safety boundaries could be made by reducing ship’s speed or increasing safety distance limits. Oppositely, if the ship gets closer to hazards, like the cost line, we expect to see some augmentation in the readiness of the control system. In this situation, the eco-sounder should be turned on. This kind of feedforward control process also support self-organization and adaptability, when facing uncertainty or unpredicted constraints.

With interactions, learning and predictability potential is developed, trust in automation is gained, which brings no need to try to perceive all the information. However, information should be presented in a completely different fashion, based on the current context and task. This denotes, that we need to remove the mental and perceiving effort of integrating the guidance information from several instruments. Information should be presented as a pictorial representation of the track, dangers, and guidance information. The zooming and changing scale effect, as in the ECDIS or RADAR, should be minimized to enhance memory and visual attention. Additional design parameter must consider:

- Directed attention;
- Information fitted in its context;
- Familiar semantic;
- Exploration of new attributes for the features;
- Reduction of noise and non-target distractors;
- New events must be easily perceived in a cleaner presentation, and
- The presentation should reflect the undergoing tasks.

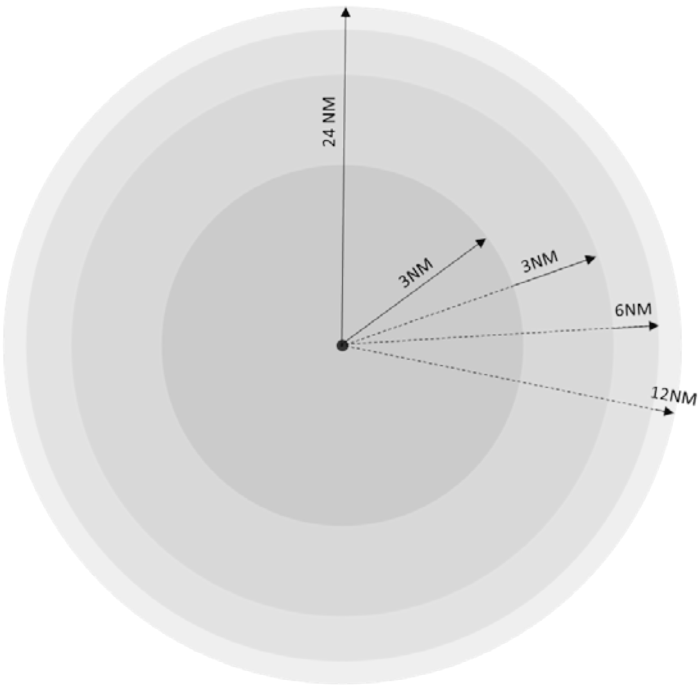

Figure 29 - Multi scale information display concept

In view of the previous requirements, one perceived solution is the design of a multiscale display. In this concept, depicted in Figure 29, all information is displayed in a single view, however contents details will vary in function to the ships distance and speed. To avoid operator's confusion in the interpretation of progressive scale (lens effect), the space between each ring have the same scale.

One relevant point is the relation of each area to the required type of control and the processes found in the navigation functions (Figure 8). For instance, the 3 nautical miles scale (NM) should present information that directs reactive control, mostly based on onboard sensors observations and relevant contextual information. As we move to the outer limits, different categories of information and presentation are displayed, like elements that might determine changes in the route plan.

With this type of presentation eliminates there is no need for zooming (ECDIS) or changing scale (RADAR). Another feature is the definition of the inner scale, set by the human controller, it should reflect the level of readiness. Readiness is related with the time and resources required to avoid any specific hazards (vessels, coast line, etc.). For example, if the JCS is slow to assess and respond to situations, it must expand the inner scale to provide more information and time to evaluate and decide. The inner scale, defined by the human operator, can be interpreted by the automated agents as a safety boundary threshold, adjusting the type of support that is provided to the human accordingly to the values that were set.

The following figures exemplifies an example of the effect of removing the classical chart representation and setting the information display based on the context and task, in this case:

- Monitoring the close dangers to support *reactive* decision
- Monitoring the plan to support the *proactive* decision

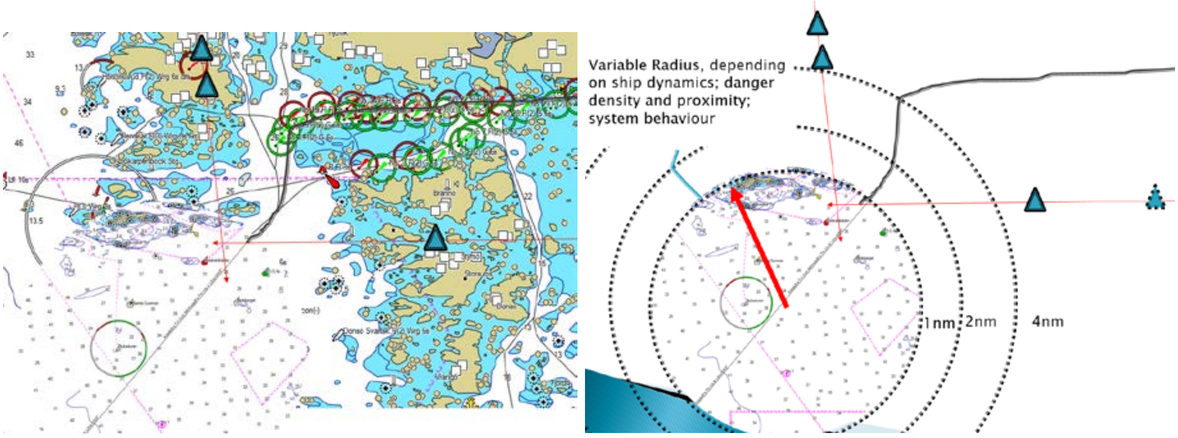

Figure 30 - Example of context/task-based representation.

From the results of study III, we may see that the instructors in the survey also addressed five of the most common NTS. Those are also closely related with causality factor revealed from the analyses of the accidents reports. Subsequently, from the correlation analysis of the literature review, surveys and accidents analysis, five NTS categories were defined: Leadership, Situational Awareness, Communications, Team work and Decision making.

Some may argue that the methodology should have include a survey directed to the practitioners, this option was discussed and considering the extensive studies already made based on professional focused group, we proposed to follow that work and combine it with different perspectives, even though with some professional opinions – the lecturers. We should note that several factors identified in the analysis of the accidents, have already been addressed by the Navy, mostly throughout the implementation of new procedures, instructions, changes in the training programs and qualification processes.

The challenges presented to the future naval officers have large similarities to other domains. For instance, from the last World Economic Forum (World Economic Forum, 2016) report, it becomes clear how the emerged NTS are close to the abilities and soft skills identified in cross industry studies (Figure 31).

Figure 31 - Soft skills trends identified by WEF (from: http://reports.weforum.org/future-of-jobs-2016/shareable-infographics/).

Both surveys, made in study III, show that simulated training demands more involvement from the instructors, or a different type of pedagogical approach. Students' and instructors' perceptions are in line with what Emad (2010) and Magdy (2016) claim over a more involving role of the lecturers in the team under training. Students undertaking tasks and working as a team in the simulator, seek for more cues and guidance than the ones provided by the warnings and alarms related with the effectiveness of their actions and decisions. This involvement is quite like the training that is provided aboard, with the trainee deeply integrated in the ship's team. Aboard we usually found one or two trainees as part of the bridge team. In the simulator, instructor should be with the trainee team, so they can learn alongside with the instructor.

6.4 Methodology

Grounded theory was used to conceptualize the function of navigation based on standard professionals' behaviours and interactions between all the maritime stakeholders. As stated by (Glaser & Strauss, 1967; Patton, 2002; Strauss & Corbin, 1990) the coding process of Grounded Theory is time consuming, the observer is constantly influenced by the observations to a shifting degree, which constantly feed a laborious work of relating and integrating categories into concepts and larger theory.

Some uncertainty of the results is expected and to some extent desired, as the capturing and unfolding of as many elements as possible was desired, as suggested by Patton (Patton, 2002).

Additionally, throughout the data collection and coding processes, the relations between the classification scheme and mental preconception can dictate some influences over the analysis. Another bias is due to the observer presence, with possible influence on participants' responses, by avoiding the description of inadequate behaviours, or having a compulsory need to report the practice of correct and expected procedures. Nevertheless, the interviewer had to be more consciously controlled to avoid judgements on participants' statements and adopted procedures, wondering if the they could be more open about their experience if they didn't know that the researcher was a mariner.

Observation and measurement of a specific domain situation or phenomenon depends on how they are understood and explained, which mean that a previous conceptualized model is required to support the description of the significant features of the observed system. However, as explained by Dekker & Hollnagel (2004, p. 82), the model may also constrain the unfolding process of the observed system. When applying grounded theory, throughout the field observation, conduction of interviews and coding process, the relations between the classification scheme and mental preconception (internal model) will somehow dictate some influence over the analysis. However, the domain empathy owned by the researcher, as professional mariners, sustained and facilitated the understanding and interest of the participants' response and experience.

Even though the general assumption that literature reviews should be done or consolidated following the use of grounded theory, it is also recognized that it should support the analysis of the categories (Glaser & Strauss, 1967; Patton, 2002). Leaving the literature for after for not having prior ideas might seem a naïf view. Consequently, the author adopted approach was to perform the open and axial coding process alongside the literature reviews.

7 Conclusions

This thesis aimed to explore maritime navigation as an activity conducted in a Socio-technical system. It intends to deliver a deeper understanding and characterization of the control processes used to support safe and efficient navigation. It focussed on how navigation is carried out by mariners, addressing the arrangement made in training and the use of artefacts.

The mains contribution lies in presenting a framework of maritime navigation, exploring the control processes in the different levels of the maritime socio-technical system. In the view of safe operations, interactions between stakeholders are clarified, trying to determine how they influence safe navigation. This systemic view is then analysed from the perspective of the ship, considering it as a Joint-cognitive system.

Planning is considered a fundamental process in the maritime Socio-technical system, because it facilitates the interactions between the different control level. It strengths the integrity and clarity of communications and enhance predictability of the different control agents. In the maritime domain we need to foster both top-down and bottom-up initiatives. If we want to encourage adaptability and be sensible to the real context of operations, bridges systems must be designed in a way that it facilitates bottom-up initiatives.

Onboard, navigation is undertaken by a JCS comprising human and automated controls. However, looking at the current developments in automation in conjunction with the maritime accidents, there is a clear need to review their role and the design of navigation system. We need to further study the designs of all technological artefacts envisaged in the eNavigation bridge concept, namely those that involve Human Computer Interaction.

Nautical charts are in place for over five centuries and even in the digital chart display system their representation is still very much similar. The amount of digital information obtained from databases, sensors and shore-based services in pair with reduction in manning and automation, demands for new and innovative ways for the visualization of maritime navigation information. This thesis attempts to deliver new design strategies and solutions for the representation of navigation information.

Finally, the studies on NTS in bridge teams allows for the understanding of human role in JCS and how to enhance human capabilities required for better control of navigation. Moreover, those “properties” of individuals and teams need to be addressed when designing unmanned vessels. If we understand that they are relevant in the current JCS, we need to ask how they would be implemented in unmanned system.

At the end of this journey, new challenges are on sight. Safety is still a dominant issue, one remaining question concerns with how safety is negotiated between actors with different motivations at sea. In contrary to other transport fields, as air, train or road, at sea the space is shared by several stakeholders, having dissimilar motivations. Consequently, their perception of safety and the factors that are considered in that assessment, may vary considerably. For instance, between fishing vessels and shipping, or between offshore renewable energy park or aquacultures and shipping. Negotiation of safety boundaries need are also to be better understood for areas where manned and unnamed vessel must operate commonly in the same areas.

Interactions between mariners and information systems need to be reviewed. The concept of inverse navigation decision support tool may deliver a changing paradigm of navigation artefacts. Further studies are required for the design of new forms of information visualization and interactions. This should be thought not only in the light of the navigator role, but also from the perspective of remote controlled vessels.

Research in the field of NTS provided valuable contribution in the identification and development of individuals skills and behaviours. However, we need to better understand how those NTS work in teams composed by human and automated agents. How can we develop leadership, team work, delegation and communication within these teams?

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